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ENERGY
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ENERGY CONSERVATION IN CITRUS PROCESSING

Technical Progress Report, October 1, 1979—March 31, 1980

June 15, 1980

Work Performed Under Contract No. AC03-79CS40263

Sunkist Growers, Inc.
Ontario, California

and

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

U. S. DEPARTMENT OF ENERGY

Division of Industrial Energy Conservation

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ENERGY CONSERVATION IN CITRUS PROCESSING

TECHNICAL PROGRESS REPORT

For the Period
October 1, 1979 - March 31, 1980

June 15, 1980

Prepared for
U.S. Department of Energy
Office of Industrial Programs
Agricultural and Food Processes

by

Sunkist Growers, Inc.
Ontario, California

and

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Prepared by Sunkist Growers, Inc., Ontario, California as prime contractor, and the Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, as subcontractor.

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1. INTRODUCTION

The Sunkist Citrus Plant in Ontario, California processes about six million pounds of citrus fruit per day to make a variety of products which include frozen concentrated juice; chilled, pasteurized, natural strength juice; molasses from peel; dried meal from peel; pectin; citrus oil; and bioflavonoids. The entire plant typically requires about 50×10^6 kilowatt-hours of electrical power per year and about 10×10^{11} BTU per year of thermal energy from the combustion of natural gas or fuel oil. Presently, all electrical power is purchased from Southern California Edison and all the thermal energy is produced on-site in the furnaces of steam boilers and of dryers.

The preferred fuel for steam generation and for drying has been natural gas. However, the price of natural gas is being deregulated, resulting in a very rapid escalation of fuel costs. Since citrus fruit processing is presently an energy intensive operation, the substantially higher cost of fuel results in much higher processing costs and ultimately in higher market prices for citrus products. Some products may be discontinued if the cost of fuel makes them too expensive.

The Sunkist citrus fruit processing plant was originally designed when natural gas was considered to be plentiful and was the most economical energy source. Consequently, energy utilization efficiency was not a predominant factor in its original design nor in the original design of other types of food processing plants. The energy intensive operations at the Sunkist plant include concentration, drying, and refrigeration.

An examination of the manner in which these operations are executed and the manner in which their energy requirements are satisfied provides an opportunity for the application of innovative system concepts which will significantly reduce the total energy demand of the plant. These concepts are based on available technology. The evaporation, drying, and refrigeration operations in citrus processing are typical of other food processing industries, and energy conserving systems developed for citrus processing could be adapted to other types of food processing.

2. OBJECTIVE

The principal objective of the work is to identify an economically viable alternative to the existing method of meeting the energy requirements of citrus fruit processing that will substantially reduce the overall energy usage of citrus processing plants. This objective will be accomplished in a two-phase project consisting of a systems definition study in phase one and a systems evaluation study in phase two. The project is designed to identify the overall configuration, equipment specifications, the analytically predicted performance and operating characteristics, and the projected total cost of several alternative systems. This information provides the basis for the selection of the system that is most desirable, both in terms of economic viability for the citrus processing industry, and of reduced energy usage. The final results of the project consist of the selected alternative system, a strategy for its implementation, and the technology transfer activity.

The project is structured so that currently available components are used in different arrangements to constitute the different types of alternative systems. The components which will make up the alternative systems include: evaporators, dryers, refrigeration units, heat pumps, heat engines, heat exchangers, thermal storage units, and ancillary components. These components will be used to form the five operational units of the citrus processing plant. These operational units are: evaporation, drying, refrigeration, pasteurizing and canning, and the plant electrical load that consists of operations such as conveying and juice extraction. The five operational units are then interrelated to varying degrees with respect to energy exchange to form different types of alternative systems. These alternative systems differ from existing systems in that they make optimum use of thermodynamic regeneration, cascaded energy utilization, and thermal storage to minimize the energy usage of the citrus processing operations without changing the product process stream state variables.

3.0 APPROACH

3.1 Types of Alternative Systems

The study of alternative systems to reduce energy usage in citrus processing focused on the manner in which the energy requirements of the various basic operations in citrus processing are satisfied. These fundamental energy requirements are taken as they presently exist, except where there is an advantage in changing a particular operation where known flexibility of process requirements may be advantageously exploited. The different types of alternative systems for meeting these operational energy requirements will consist of different arrangements of some or all of the following major components: evaporators, dryers, heat engines, heat pumps, refrigeration machines, heat exchangers, compressors, and pumps, thermal storage units, and microprocessors. The alternative systems feature cascaded energy utilization wherein the heat source, work absorbing or producing and heat rejection characteristics of the various components and subsystems are properly matched to satisfy the specific energy requirements of the basic operations of citrus processing. Where operationally and economically feasible, and in addition to cascaded energy utilization, the alternative systems will incorporate thermodynamic regeneration, thermal storage, and microprocessor control to minimize the plant's overall energy usage.

The basic operations of citrus processing and their supporting operations which will be considered in this project are:

a. evaporation of citrus juice to produce a concentrate, and evaporation of peel liquor to produce molasses;

b. refrigeration for chilling, freezing, and storage of citrus juice products;

c. pasteurizing and canning of citrus juice;

d. drying of peel and pulp to produce dried citrus meal;

e. the various electrically driven operations, such as conveying, grinding, pressing, juice extraction, centrifuging, fluid pumping, compressing, pelletizing, and ventilation;

f. the supply of energy to the basic operations by means of an energy supply subsystem which may be based on purchased electrical power and boiler generated steam or it may incorporate a heat engine.

These basic operations are performed by individual assemblages of components that are referred to as "Operational Units". The operation units that are to be considered in this study are shown in Figure 1 as they exist within the present energy utilization system of the Sunkist plant in Ontario, California. Each of the alternative energy utilization systems to be considered in this study is comprised of the five operational units shown in Figure 1, which are Evaporation, Pasteurization and Canning, Refrigeration, Drying and the Plant Electrical Load. The energy supply subsystem, which is a separate entity, will be partially or wholly incorporated as part of the operational units of certain types of alternative systems. The alternative systems to be considered in this project are classified in four general categories, denoted as Central, Modular, Integrated, and Combined. These categories are distinguished by the extent to which the operational units of the citrus processing plant are interrelated with respect to energy usage and flow.

The Central systems feature a separate central energy supply subsystem from which the energy requirements of the operational units are supplied. The conceptual layout and energy flow paths for one of the several central systems to be considered are illustrated in Figure 2.

A Modular system consists of the five operational units wherein an individual energy supply subsystem is contained within each separate operational unit. The aforementioned balance between thermally-driven and work-driven operations within the modular operational units will be adjusted to optimally exploit the heat source, work producing, and heat rejection characteristics of the energy supply subsystem. An illustration of a Modular system is shown in Figure 3.

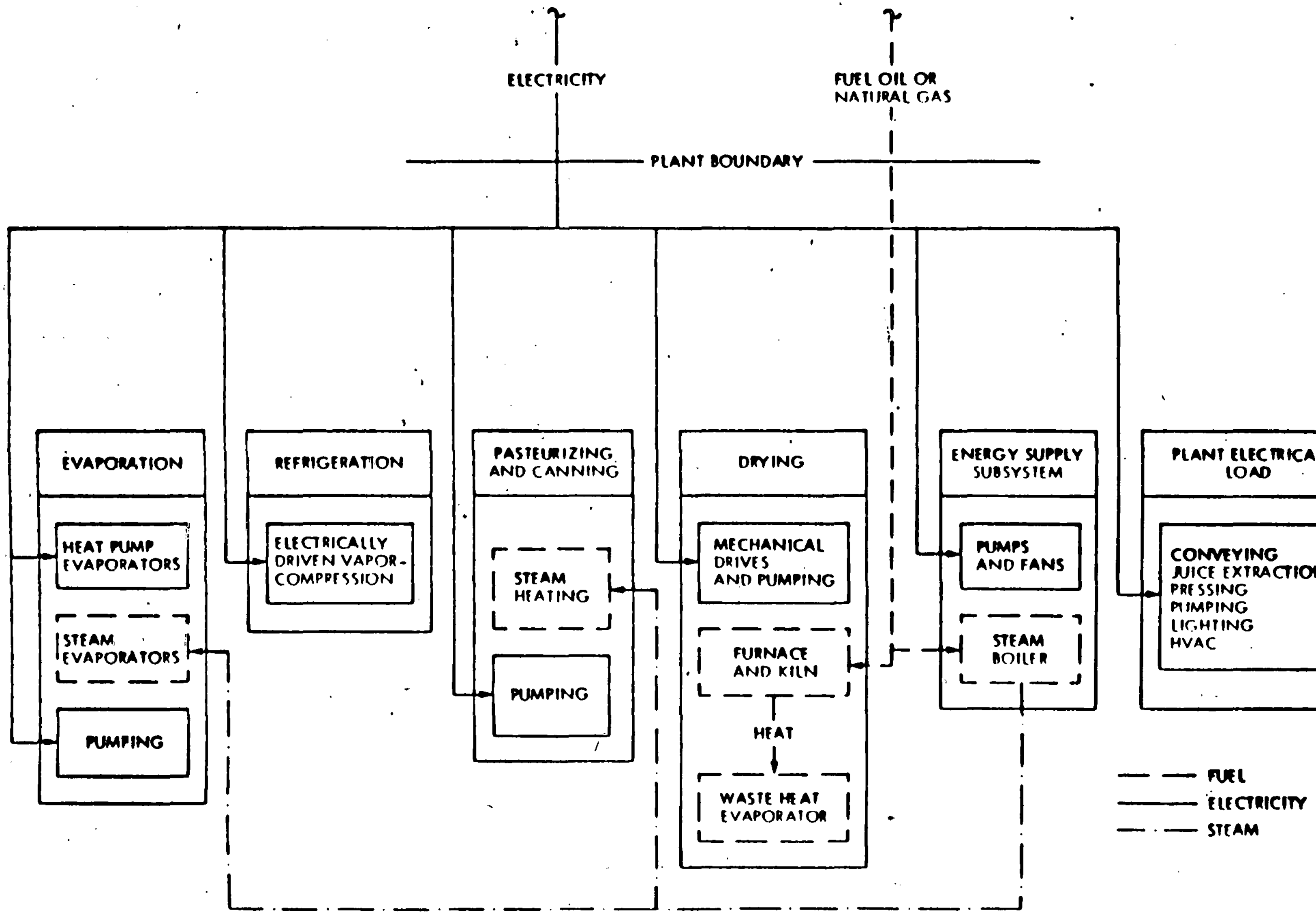

FIGURE 1: Existing operational units and energy flow paths of the Sunkist plant in Ontario, California

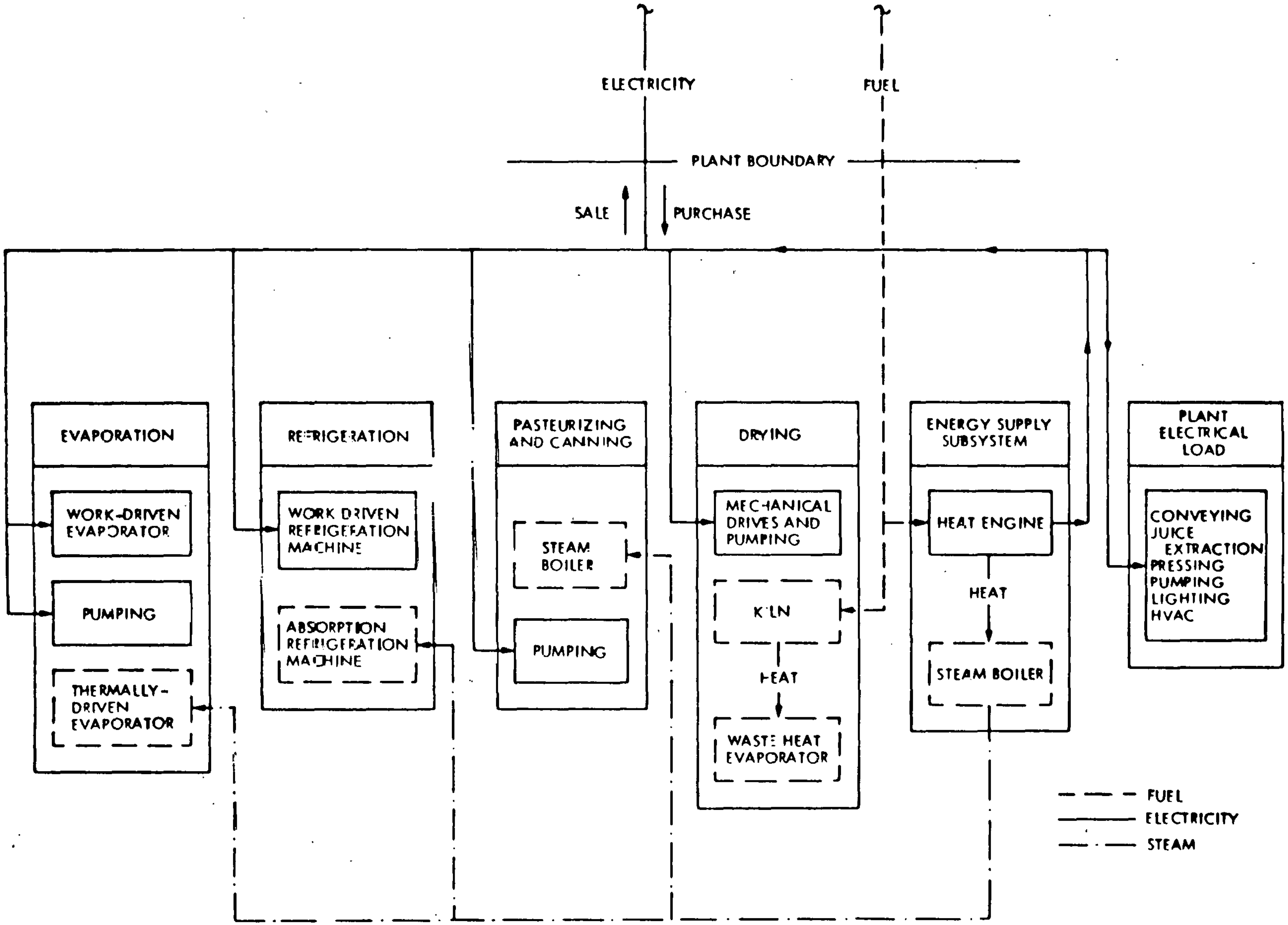

FIGURE 2: An illustration of the concept of Central energy utilization systems in which the energy supply subsystem could incorporate either a Rankine, a Brayton, or a Diesel heat engine.

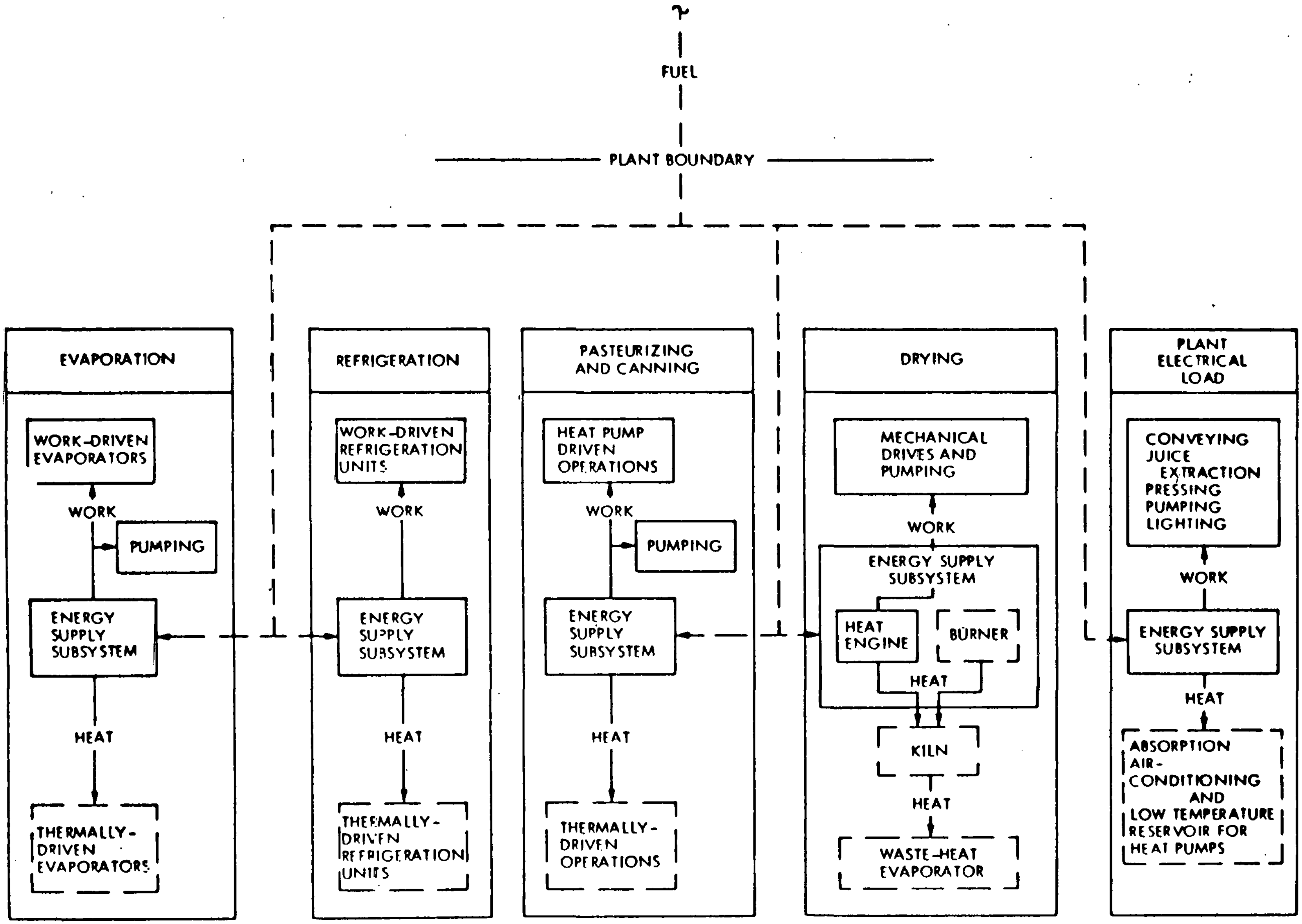

FIGURE 3: An illustration of the concept of Modular energy utilization systems in which the energy supply subsystem could incorporate either a Rankine, a Brayton, or a Diesel heat engine. Each module functions largely as an independent unit.

The Integrated systems consist of operational units of which at least one incorporates an energy supply subsystem. The five operational units are interrelated such that their heat and work requirements are met either with a reduced need or completely without the need for a separate central energy supply subsystem. Within each operational unit both the balance between the thermally-driven and work-driven operations and the type of heat engine may be selected to produce a net surplus or deficiency of heat or work which will match a reciprocal heat or work requirement of other operational units. An example of an integrated system in which the operational units are configured and interrelated so that no separate energy supply subsystem is required and no electricity is exchanged with the utility is shown in Figure 4.

The Combined systems consist of the five operational units and a separate energy supply subsystem with the possibility of electricity exchange with the utility company being considered. The Combined systems will be configured and arranged to achieve either minimum total cost of minimum total energy usage under the requirement of maintaining an acceptable rate of return on invested capital. The Combined systems will be based on selected operational units that were configured for the other system categories. An illustration of the concept of Combined systems which is representative of several such systems to be considered is shown in Figure 5. The Combined system illustrated makes use of a modular evaporation operational unit, while the refrigeration, the drying, and the pasteurizing and canning operational units are from an Integrated system, and the plant electrical load is met with electricity from the public utility. It is likely that some version of a Combined system will prove to be the most attractive of the alternative systems.

3.2 Components of Operational Units and Subsystems

The components from which the operational units and the energy supply subsystems will be synthesized are listed and briefly described below. These components are the basic elements that will be used in different combinations and arrangements to form all the alternative systems:

A. Evaporators: Evaporation operations may be driven with energy in the form of either heat or work, and a single evaporator unit may utilize both thermally-driven stages and mechanically-driven stages.

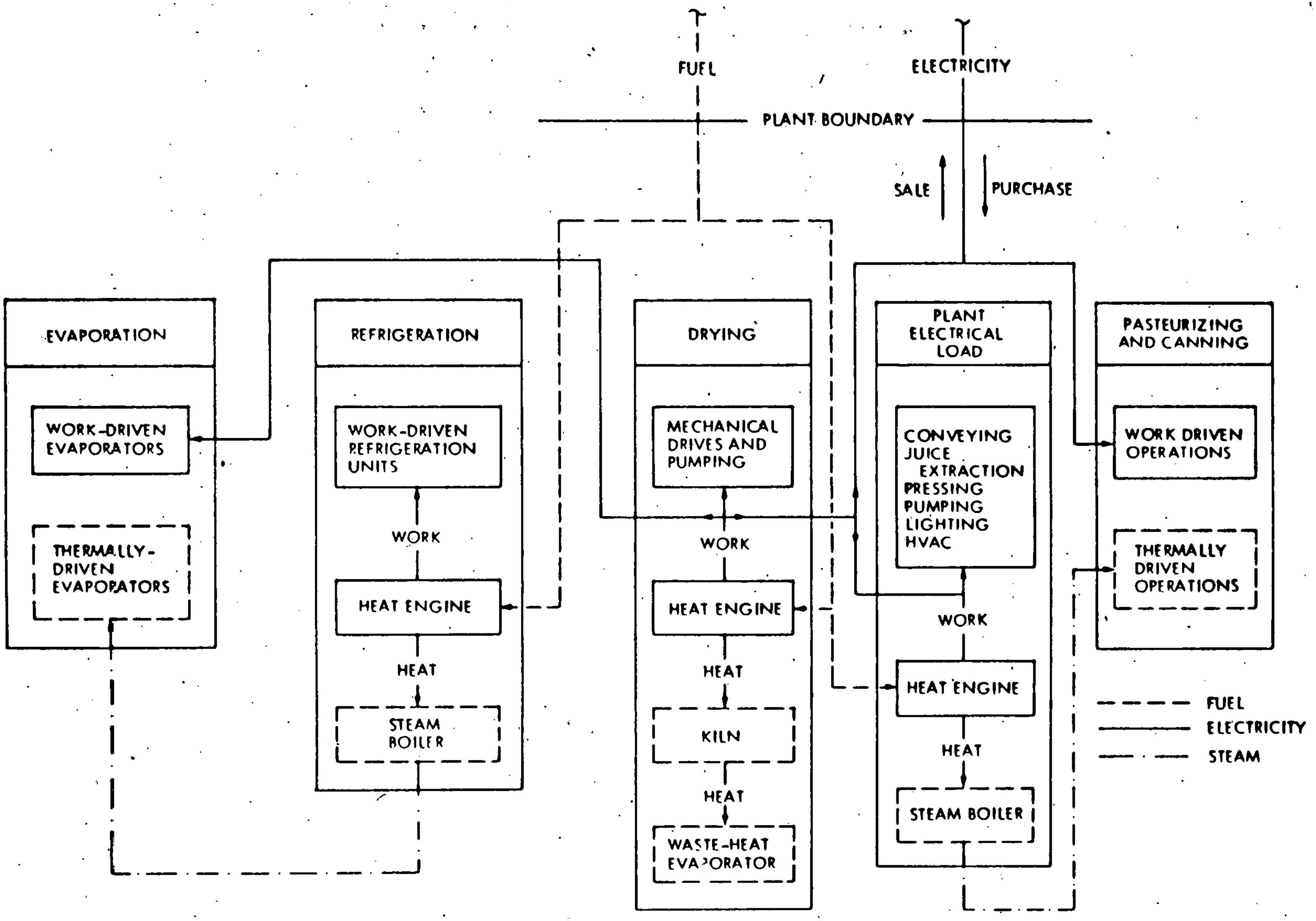

FIGURE 4: An illustration of the concept of integrated energy utilization systems. This particular example incorporates a Brayton engine in the Drying operational unit, while the type of heat engine used in the Refrigeration and Plant Electrical Load operational units may be either a Rankine, a Diesel, or a Brayton engine.

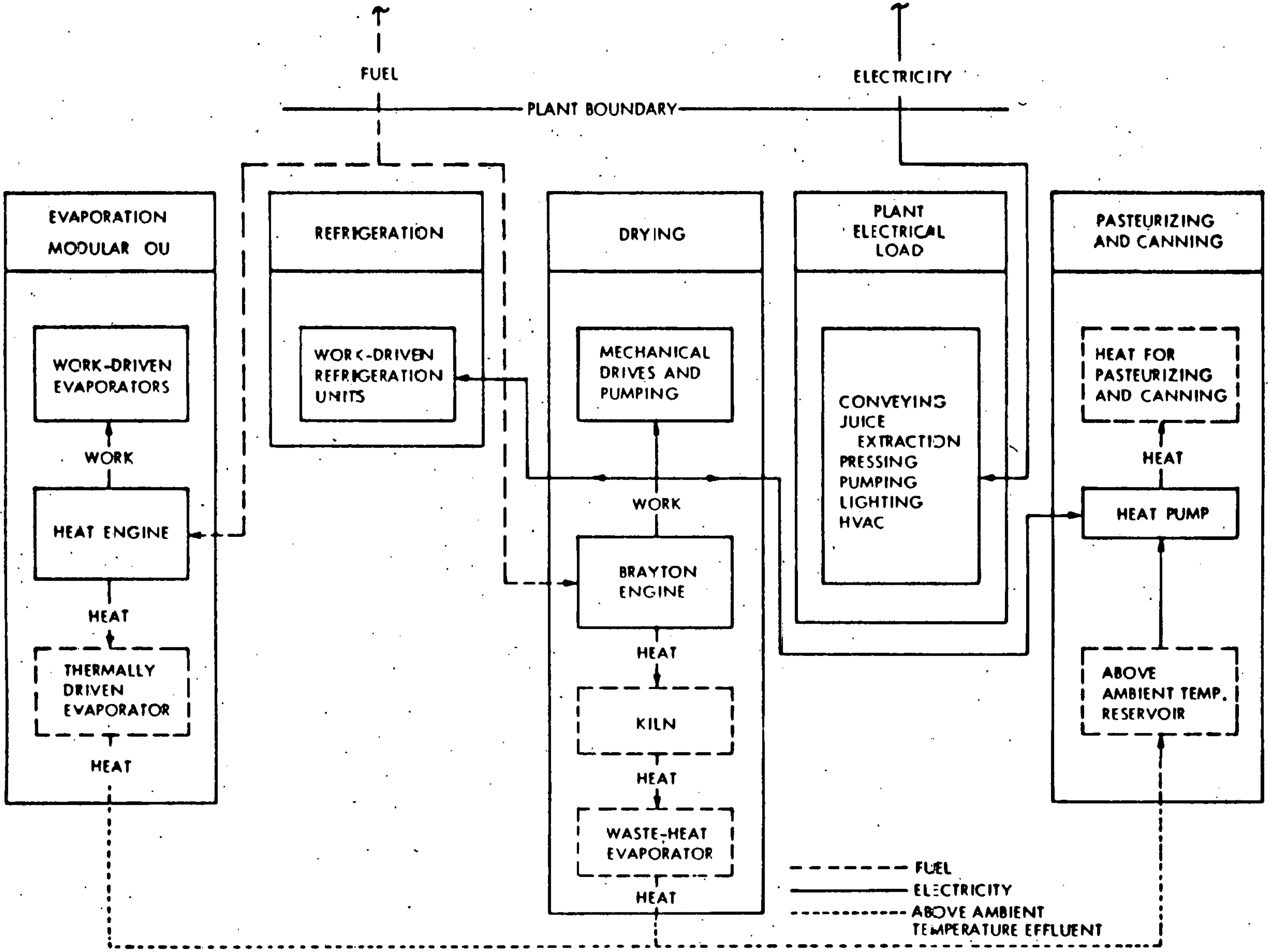

FIGURE 5: An illustration of the concept Combined energy utilization systems. In this system, the Evaporation OU is Modular, while the excess work from the Drying OU is distributed as electricity to the Refrigeration OU and the Pasteurizing and Canning OU. The plant electrical load is met with power from the Utility.

Multiple-effect, thermally-driven evaporators and mechanically-driven evaporators of both the vapor-recompression type and the heat-pump type will be analyzed for use in the evaporator subsystems.

B. Refrigeration Machines: Refrigeration operations may also be driven with either heat or work. Thermally-driven absorption refrigeration and two types of mechanical refrigeration, vapor-compression and regenerative gas-expansion will be considered for the alternative systems.

C. Heat Pumps: Heat pumps are work-driven devices which function to elevate heat from a low temperature reservoir to a higher temperature reservoir. For example, consider that a fluid effluent stream is available at a temperature of 200° F (93° C). A heat pump could be employed to recover a portion of the heat of the effluent stream to supply some operation that requires heat at a temperature of 300° F. (149° C).

D. Thermal Storage Units: Different types of thermal storage units will be parameterically examined for use in the alternative systems to mitigate any energy usage increase resulting from transient processing load and duty cycles.

E. Heat Exchangers: Heat exchangers are essential subsystem components whose performance will be parametrically characterized. Waste heat boilers and fluid effluent heat recovery units are examples of heat exchangers to be utilized in the alternative systems.

F. Dryers: The drying operations at the Sunkist plants require large amounts of heat at fairly high temperatures. The effort of this study will be directed toward the manner in which the heat requirements of the drying operation are met and, except for minimizing direct thermal losses, will not explore extensive changes in the drying operation itself. Among the options to be examined is the use of gas turbine exhaust to provide heat for the drying operation.

G. Heat Engines: The three fundamental types of heat engines upon which the energy supply subsystems can be based are the Brayton (gas turbine), Diesel, and Rankine (steam turbine). These engines have markedly different characteristics and are one basis for variation within a category of alternative systems.

In addition to the major subsystem components described above, the alternative systems will incorporate such components as compressors, pumps, steam ejectors, and electric motors.

4. WORK PLAN

4.1 Overview of the Project

The proposed work is being carried out in two phases, each phase requiring one year to complete. The first phase is a systems definition study, which terminates with a general description of alternative system concepts and a preliminary economic and energy usage evaluation. The second phase is a systems evaluation study in which the alternative system concepts provide the basis for a more detailed performance analysis and optimization via computer simulation. The energy usage, operating cost, initial cost, and system operating characteristics thus established serve as the basis for the evaluation of the alternative systems and the subsequent selection of the most desirable system.

4.2 Task Descriptions - Phase I Systems Definition

The individual tasks that make up the two phases of this project are listed in Table 1, and a more detailed description of the technical work to be performed in each of the tasks of phase I is given below. The work that has actually been done through March 1980 is described in a subsequent section of this report.

Table 1. List of Tasks Comprising the Project

TASK NUMBER AND TITLE		DESCRIPTION OF ACTIVITY	
	PHASE I	SYSTEMS DEFINITION	JPL RESPONSIBILITY
I.A	Identification of Constraints, Requirements and External Factors	● Environmental and product quality factors ● Government regulations ● Establishment of total cost function ● Future energy cost and availability projections ● Uncertainty assessment of projections	Assist Sunkist in establishing the total cost function, the energy cost and availability projections, and the uncertainty assessment
I.B	Characterization of Basic Operations	● Analytical and experimental determination of process state variables and throughput in existing system	Assist Sunkist in identifying the measurements to be made and in the formulation of the data reduction algorithm
I.C	Thermodynamic Analysis of Operations and Components	● Formulation and validation of analytical models of components and operations	JPL will perform the analysis based on the characterization provided by Sunkist
I.D	Synthesis of Alternative Systems	● Formulation of conceptual layout of alternative systems and preliminary prediction of performance and operating characteristics	JPL will perform the systems synthesis based on the criteria provided by Sunkist
I.E	Preliminary Evaluation	● Selection of more promising alternative systems on basis of preliminary economic and energy usage characteristics	Assist Sunkist in preliminary application of total cost function and in the establishment of energy usage and operating characteristics of alternative systems

Table 1. (continued)

TASK NUMBER AND TITLE	DESCRIPTION OF ACTIVITY	
PHASE II	SYSTEMS EVALUATION	JPL RESPONSIBILITY
II.A Simulation of Components and Operations	● Formulation of computer codes based on analysis of Task I.C	JPL will formulate the computer codes to be validated according to criteria provided by Sunkist
II.B System Model Integration	● Assemblage of component simulation codes to form complete system models for alternative systems identified in Task I.E	JPL will assemble the component simulation models to form system models representing the alternative systems. Sunkist will assist in system model formulation and provide criteria for checkout
II.C System Optimization	● Variation of system configuration specifications to establish the system configurations that yield (1) minimum total cost and (2) minimum energy usage under the requirement of economic viability	JPL will perform the technical work required to exercise the system models according to the optimization criterion developed by Sunkist
II.D Implementation	● Assessment of impact of implementation of alternative systems on existing processing plant; acquisition time phasing, construction scheduling and planning, long term uncertainty analysis	JPL will provide technical support regarding system characteristics
II.E Evaluation and Selection	● Selection of a system to be put into use based on: ● total cost function ● rate of return on capital ● implementation options ● uncertainty assessment	JPL will assist Sunkist in establishing the quantitative selection criteria

Table 1. (continued)

TASK NUMBER AND TITLE	DESCRIPTION OF ACTIVITY	
PHASE II	SYSTEMS EVALUATION	JPL RESPONSIBILITY
II.E (continued)	• energy conservation assessment • capital requirements and risk analysis	
II.F Technology Transfer	• Assessment of applicability of study methodology, techniques, and optimum systems to other food processing industries, and communication of study results to food processing industry and technical community via: • industry workshop or technical conference discussion • project report • technical paper	JPL and Sunkist will share equal responsibility in preparing for and carrying out the Technology Transfer Task as described

TASK I.A: Identification of Constraints, Requirements and External Factors.

This task is concerned with identification and assessment of the criteria that the alternative systems must meet in order to be acceptable. Constraints are those criteria that are stated as initial assumptions or starting premises. Requirements include those criteria which are externally mandated, such as air pollution or wastewater standards, FDA standards regarding food processing, and government safety regulations. Requirements also include internally imposed mandates such as product quality standards, plant operating procedures, economic criteria, and financing practices. An important activity in Task I.A is the establishment of the total cost function. The total cost function will properly weigh the operating cost, the initial cost, and the expected service life of the alternative systems. This activity must include consideration of the rate of return on invested capital, interest rates on borrowed capital, sinking fund interest rates, and assessments of financial risk.

External factors must be assessed and considered in the synthesis, optimization, and selection of an alternative system. External factors include matters of policy, such as that of the Public Utility Commission and the Electric Utility Company regarding industrial power generation, and matters of fuel cost and priority. Other external factors which must be addressed are the projected costs of utility supplied electrical power and of the different types of fuel expected to be available for use in the plant. In addition, the uncertainty of the projections of fuel and electricity costs must be assessed.

The results of Task I.A are utilized in the synthesis of the alternative system concepts and in the preliminary evaluation of the alternative systems.

TASK I.B: Characterization of Process and Subsystems

The basic operations of citrus fruit processing shall be characterized in terms of inlet and exit states of the various process streams and the values of the thermodynamic variables at critical points along the process flow path. The required thermodynamic variables and other parameters such as fluid flow rates and electrical power consumption must be experimentally measured in the existing subsystems, operational units, and components if they are not presently being measured or cannot be analytically calculated from well established information. The major operational units that must be characterized are evaporators, dryers, refrigeration systems, the low temperature heating loads such as pasteurizing and canning, and the electrical loads of compressors, pumps, and mechanical drive units.

The drying operation is presently linked with a waste-heat evaporator which produces molasses from peel liquor. The present operation represents a significant effort toward energy conservation by utilizing the heat absorbed by the water evaporated from the moist peel inside the dryer to subsequently provide the heat required to concentrate the liquor that is pressed from the peel prior to its entering the dryer. The existing dryer-waste heat evaporator combination must be thoroughly characterized to enable alternatrives to the presently used furnace to be examined as a source of hot gas for the dryer. Dryer parameters which are required include solid material flow, gas flow, gas temperatures and the moisture content of the solid and gas at both the entrance and the exit of the kiln. Residual oxygen and carbon monoxide concentrations in the furnace will be measured to evaluate combustion efficiency.

The refrigeration operation will be characterized in terms of capacity (heat removal/unit time) required to chill or freeze the product streams and to maintain the frozen products at their storage temperature. The measurements required will enable the presently delivered refrigeration capacity and the electrical power consumption of existing units to be determined.

The energy requirements of operations now being met with steam heating such as pasteurizing and canning may be established from the mass flow and the thermodynamic state of the supply steam. The electrical power requirements for pumps and compressors may either be analytically determined from well established performance characteristics, or experimentally measured as is appropriate.

The results of Task I.B will be given as detailed process flow charts and energy flow diagrams with accompanying graphs and tables as required to describe the energy requirements of the basic processes and operations both with and without consideration of the operating efficiencies of existing equipment. This information will be subsequently used in Tasks I.C, I.D, and II.A as a guidance and input for the thermodynamic analysis, the synthesis of alternative systems, and the formulation of the computer simulation codes for the various components and subsystems.

TASK I.C: Thermodynamic Analysis of Components

Task I.C. consists of applying the principles of thermodynamics and fluid mechanics to the processes that occur within each of the components enumerated in Section 3.3.4. Fluid-dynamic and thermodynamic equations will be applied in conjunction with physical properties data for the fluids and materials being processed.

The equations representing each component will be translated into a computer code to simulate the operation of that component. Simplified versions of the analysis for the components will be employed in the development of alternative systems, Task I.D., and in their preliminary evaluation, Task I.E.

A major portion of the effort of Task I.C will be devoted to the analyses of evaporators and dryers. The thermodynamic expertise of the key personnel at Sunkist and JPL, in addition to review and counsel by selected equipment manufacturers, will ensure that a comprehensive treatment of the technological options for evaporation and drying is achieved.

Task I.D: Synthesis of Alternative Systems

Alternative energy utilization systems which meet the operation requirements of citrus processing will be conceptually formulated in Task I.D. The synthesis of the alternative systems will consist of formulating a conceptual layout with properly matched components for each of the alternative systems. These alternative systems are four general categories, denoted as Central, Modular, Integrated and Combined.

The objective of this synthesis of the alternative systems is the minimization of the amount of energy that is utilized in the operations of citrus processing within the limits of economic feasibility.

The characterization of basic operations from Task I.B and the thermodynamic analysis of components from Task I.C will provide the quantitative information about the basic operations and the understanding of the components that are necessary to develop the alternative systems. A simplified thermodynamic analysis from Task I.C will be employed to establish the approximate performance characteristics of the alternative systems in lieu of the more complex analysis which will later serve as the basis for simulation modeling.

The output of Task I.D will consist of the general configuration and the approximate performance characteristics for several alternative energy utilization systems. The general configuration will be presented in terms of a schematic layout of the major components which comprise the operational units and energy supply subsystems with approximate values of the energy flow and the process flow among the components being given. In addition, the capacity or size of the major components will be estimated so that a representative initial cost can be subsequently established in Task I.E. The schematic layout diagram, a list of major components with their capacities and sizes, and an approximate performance analysis giving the energy utilization figures of merit of the entire systems constitutes the deliverable items of Task I.D.

TASK I.E: Preliminary Evaluation

The more promising of the several systems that were formulated during Task I.D. will be identified in Task I.E. The activities of Task I.E will include estimation of the initial costs of the various alternative systems and projection of their operating costs.

5. PROGRESS OF TECHNICAL WORK

5.1 Project Status

The project has encountered several delays. Recruiting an engineer to do the work needed in Tasks I.A and I.B at Sunkist Growers, Inc., took longer than anticipated due to the critical shortage of mechanical and chemical engineers in California. Procurement of instruments also took longer than anticipated. In spite of this the project is only slightly behind schedule.

Task I.A, Identification of Constraints, as of March 31, 1980 was about 80 percent complete. Task I.B, Characterization of Operations, at the same date was about 40 percent complete. Task I.C, Thermodynamic Analysis, was about 50 percent complete. The extensions of the completion date for each of these tasks is shown on the milestone chart, Figure 6. A significant portion of Task I.D, Synthesis, has been performed during the course of the work on Tasks I.B and I.C.

5.2 Work Completed -- Task I.A

As shown in Table 1, Task I.A includes identifying the environmental and the product quality requirements. It calls for establishing the total cost function for the economic evaluation of the alternative systems, and the projecting of future prices for fuel and electricity as well as assessing the inpact of existing and imminent Public Utility Commission rulings pertaining to fuel price and availability to industrial cogenerators. These activities are largely complete and their results are presented in the following:

5.2.1 Energy Price Projection

The last six or seven years have seen rapid increases in energy prices, especially for petroleum products. In order to credibly project future fuel and electricity prices, the following factors are considered: anticipated policy decisions affecting price regulation and tax incentives, prospects for increased fuel production, and natural resource availability. In the following paragraphs, the impact of these factors on electricity, diesel oil,

U.S. Department of Energy
Figure 6. Milestone Schedule and Status Report

ENERGY CONSERVATION IN CISTRUS PROCESSING

Sunkist Growers, Inc.
616 East Sunkist Street
Ontario, CA 91761

Contract No. DE-AC03-79CS40263
Contract Start Date: 10/01/79
Contract Completion Date: 10/01/81

		Fiscal Year 1979-80												
		O	N	D	J	F	M	A	M	J	J	A	S	
Phase I	Systems Definition													
IA	Identification of Constraints	■	■	■	■	■	■	□	□					
IB	Characterization of Operations	■	■	■	■	■	■	□	□	□	□	□	□	
IC	Thermodynamic Analysis	■	■	■	■	■	■	□	□	□	□	□	□	
ID	Synthesis of Alternative Systems									□	□	□	□	
IE	Preliminary Evaluation									□	□	□	□	□
		Fiscal Year 1980-81												
Phase II	Systems Evaluation	O	N	D	J	F	M	A	M	J	J	A	S	
IIA	Simulation of Components	□	□	□	□									
IIB	System Model Integration			□	□	□	□							
IIC	System Optimization					□	□	□	□	□				
IID	Implementation						□	□	□	□	□			
IIE	Evaluation and Selection									□	□	□		
IIF	Technology Transfer												□	

Detail by Work Breakdown Structure

Project Manager Date:

Government Technical Representative Date:

and natural gas prices are discussed, and price projections for the southern Pacific coast region are presented.

A. <u>Electricity Price</u>: Electricity prices to the Sunkist plant in Ontario have increased from 2.29¢ per kW/hr in January, 1975 to 6.2¢ per kW/hr. in June, 1980, amounting to an annual rate of increase of 19% during the five and one-half year period. A greater part of this electricity is generated by oil-fired plants. Presently, with legislation on requirements for coal plant siting in some states and its associated environmental restrictions, coal's contribution to electricity generation is not expected to be significant in the 1980-1985 time frame.

Operation of nuclear plants is controlled by Federal Power Commission which has to date issued permits for operation of a limited number of nuclear plants, while at the same time, tightening control in the issue of construction permits. Moreover, public opposition to the operation of nuclear plants has risen in response to problems and accidents that have occured in the existing nuclear plants. Therefore, in the near-term, 1980-85, nuclear generated electricity is not expected to make a significant contribution. If this is the situation, it can be reasonably assumed that electricity supplies up to 1985 will come mostly from oil-fired plants as in the past. Under these circumstances, electricity prices may be expected to escalate similarly with oil prices.

An examination of the cost of oil-generated electricity reveals that fuel cost constitutes about 75% of the total cost. It is therefore postulated that electricity prices may be expected to increase, in real terms, at 75% of the real rate of increase of oil. Hence, with a real escalation rate for oil prices of 6.9%/year and an inflation rate of 8.3%/year as projected by the Macro Model of Data Resources, Inc. (DRI), dated February, 1980, electricity prices are projected to increase at 13.5% per year during the 1980-85 ½eriod. Projected prices are shown in Table 2 and are depicted in Figure 7 as the JPL forecast. These values are a little higher than forecast from the DRI Model, also shown in Table 2 and Figure 7. This is because the DRI Model projections are for the entire Pacific region which includes some hydro-power that reduces the average price of electricity.

TABLE 2: PRICES[1] OF NATURAL GAS, ELECTRICITY & DIESEL OIL

Year	Natural Gas $/mmBTU	Diesel Oil[2] $/mmBTU	Electricity[3] $/kwhr	Electricity[4] $/kwhr	
1975	0.88	--	0.0229		Actual Prices
1976	1.19	2.27	0.0250		
1977	1.69	2.36	0.0267		
1978	1.99	2.63	0.0340		
1979	2.12	2.65	0.0380		
1980	3.70	5.36	0.06		
1981	6.0	7.58	0.0714	0.047	Projected Prices
1982	7.6	8.46	0.0850	0.056	
1983	8.85	9.26	0.101	0.063	
1984	10.1	10.25	0.120	0.072	
1985	11.35	11.35	0.143	0.080	

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[1] 1975-80 prices are actual prices paid by Sunkist in months of January

[2] 1981-85 values are DRI forecast. (See DRI 02/80)

[3] 1981-85 prices projected using annual escalation rate calculated from: rate = inflation + 0.75 (real esc. rate of oil)

[4] 1981-85 is DRI forecast

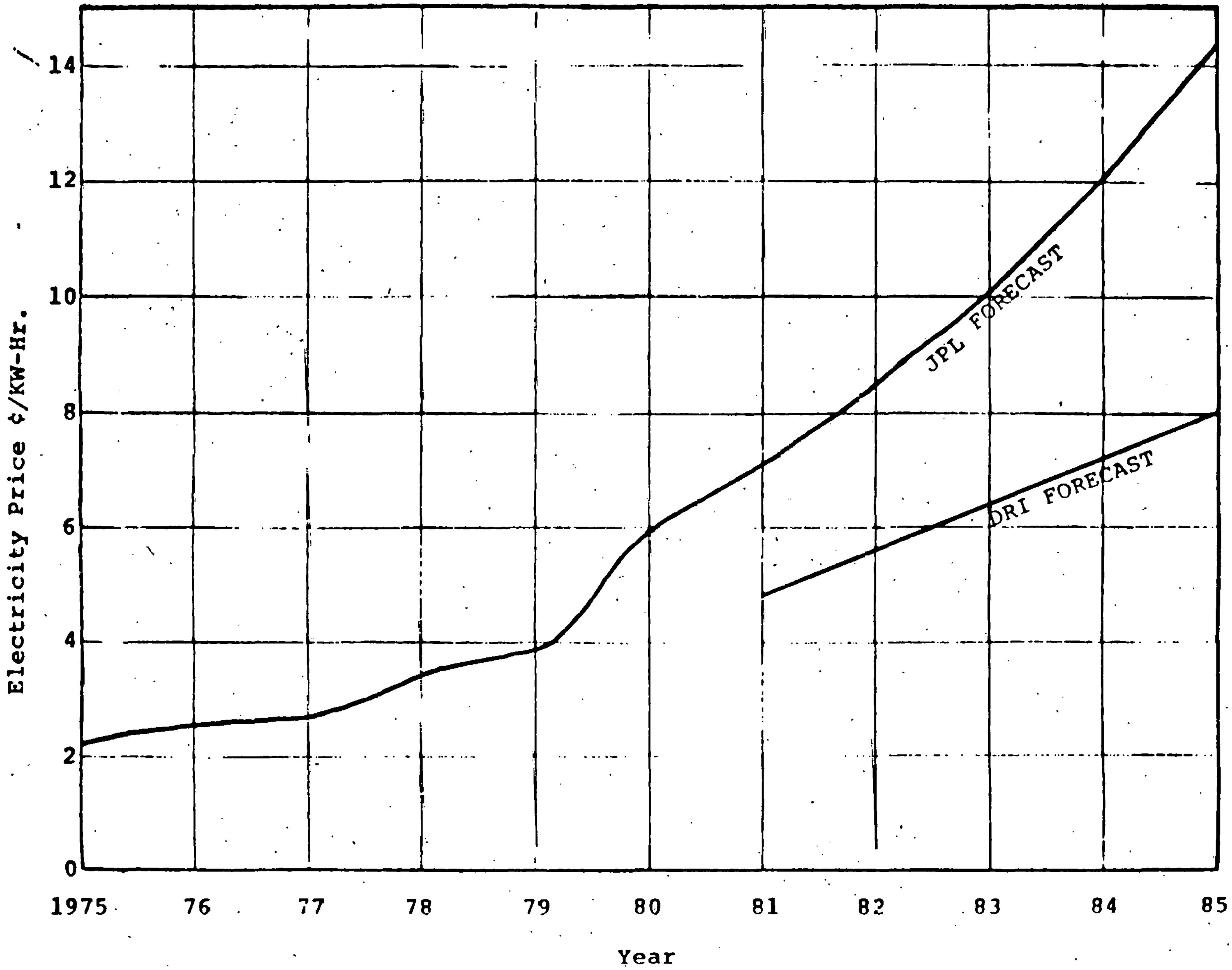


FIG. 7 ELECTRICITY PRICES TO INDUSTRY

B. Diesel Fuel: Historically, diesel fuel prices on a BTU basis have been higher than natural gas prices, as shown in Figure 8. From January 1975 to January 1980, the price of diesel fuel delivered to the Sunkist plant in Ontario jumped from 31.6¢ per gallon to 74.5¢ per gallon, which is an annual rate of increase of 18.7% during the five and one-half year period. Suppliers of this fuel anticipate no major supply difficulties.

The DRI Macro Model forecasts fuel prices for the different regions of the nation based on future assumptions for the economy. Such assumption for the February, 1980 forecast is shown in Table 3. Prices projected for the Pacific region compare reasonably well with actual prices for the past few years. Therefore, forecasted prices from this Model, shown in Table 2 and Figure 8 for the 1980-85 period are used for this study. The projected prices of diesel fuel show an annual rate of increase of 12.2% when the inflation rate id 8.3%/year.

C. Natural Gas: Prices of natural gas to the Sunkist plant in Ontario increased from $0.88 per MM BTU in January, 1975 to $3.7 per MM BTU in January, 1980. This is an annual compounded rate of increase of 33.2% during the five year period. Industry experts contend that natural gas prices will rise rapidly enough to match diesel fuel prices by 1985 when natural gas prices become deregulated. It is therefore expected that the price trend for natural gas depicted in Figure 8 will likely continue with the natural gas price catching up with that of diesel fuel by 1985.

D. Special Rates for Co-generation: Co-generation will be greatly encouraged, if the proposed rates scheduled in California are approved by the California Public Utilities Commission. Essentially, the utility would pay the Co-generator a price per KWH based on the utilities incremental costs. The Co-generator would buy electricity at the same price as other industrial customers. Natural gas may be priced to Co-generators at 1.5¢/Therm less than the price paid by utilities. This may be 20% less than the price paid by customers not Co-generating.

These rules have not been approved at this date, but the Federal Energy Regulatory Commission is pressuring the States to encourage Co-generation.

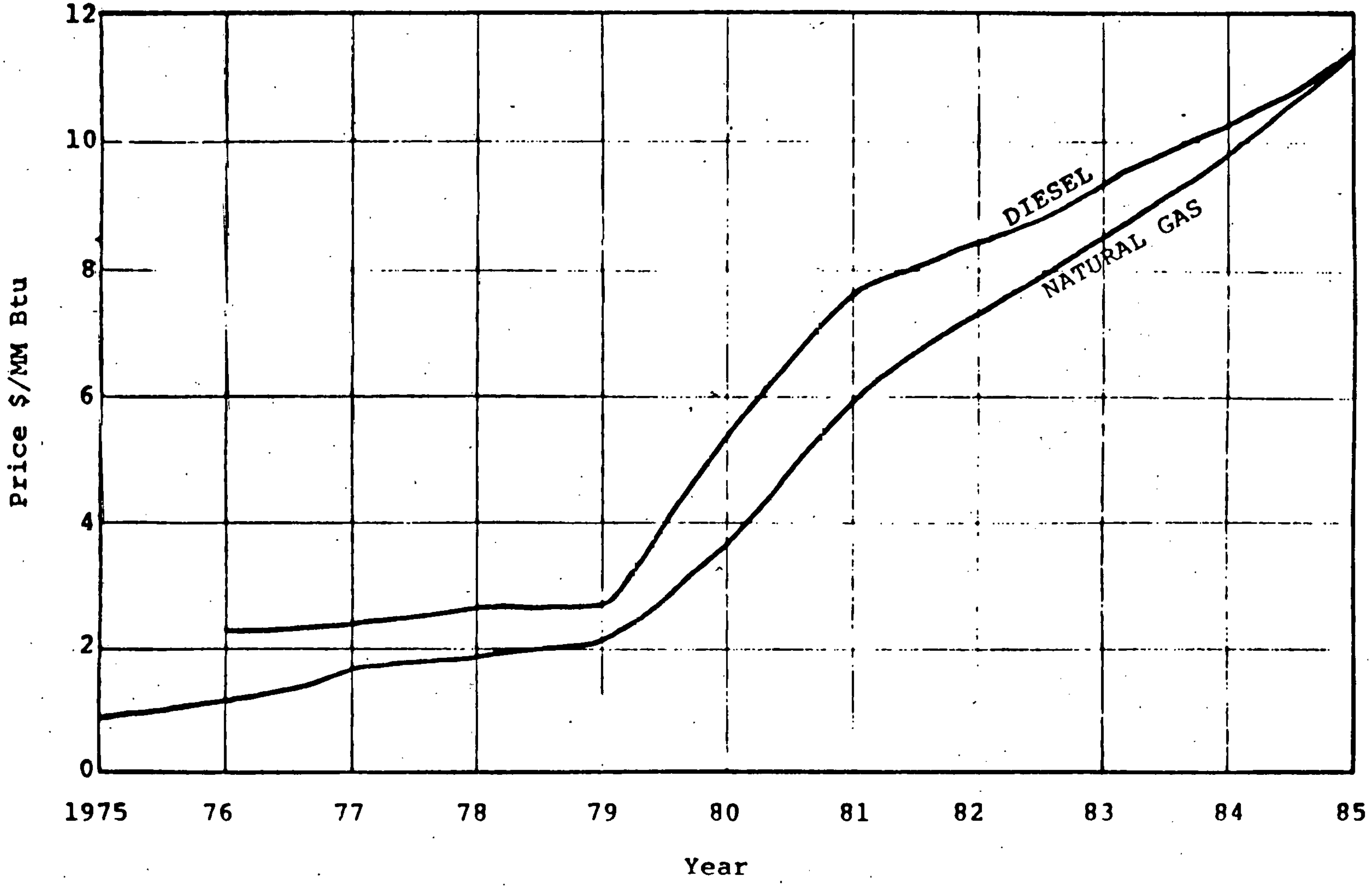


FIG. 8 DIESEL AND NATURAL GAS PRICES TO INDUSTRY

TABLE 3: DATA RESOURCES, INC.

BASIS FOR ENERGY PRICE FORECAST (2/80)

Year	Real GNP (1972$)	Implicit Price Deflator	Consumer Price Index	Wholesale Price Index	Real Disposable Income (1980$)
	Annual % Increase				
1980-85	2.5%	8.3%	8.2	9.2	2.4
1986-90	3.2	7.2	7.5	7.5	3.1
1991-95	2.2	6.3	7.0	6.9	2.4
1996-2000	2.4	6.0	6.8	6.8	2.4

Year	GNP (billions of current $)	Population (millions) US	Pacific	Personal Disposal Income (billions of current $)
1980	2,534	222	30.6	1,764
1985	4,391	231	33.0	3,007
1990	7,269	245	35.5	4,957
1995	11,041	254	37.1	7,574
2000	16,643	262	38.4	11,421

5.2.2 Atmospheric Emissions Requirements

The relevant air pollutant limitation rules are those formulated by the California South Coast Air Quality Management District (CSCAQMD) as approved by the California Air Resources Board (CARB) and the Environmental Protection Agency (EPA). The EPA does not provide specific rules, with certain exceptions, for states which are developing their own State Implementation Plan. Since California is such a state, the limitations for a specific site, such as Ontario, are embodied in the regional Air Quality Management District (AQMD) regulations. For equipment of the size range contemplated, the limitations are generally equal. The air pollution rules for the South Coast region are summarized in Table 4 in which the entries refer to the notes that appear in Appendix I.

In general, the CSCAQMD rules set explicit limits on the quantity of Oxides of Nitrogen and other pollutants that may be contained in any gaseous effluent that is discharged into the atmosphere. In addition, the Best Available Control Technology (BACT) as defined by the CSCAQMD for specific equipment is required. However, recently enacted provisions exclude certain cogeneration projects from the absolute mass emissions limits and the New Scource Review if BACT is employed. The implementation of the energy conserving systems that incorporate gas turbine (Brayton) engines and directly fired steam boilers in a cogeneragion mode is not likely to be precluded by CSCAQMD rules. However, the requirement of BACT will increase the capital cost of certain energy conserving systems. The rules and exemptions that apply to other specific types of equipment are being researched.

There are several areas of rule-making which have specifically exempted, or provided for reduced requirements when coggeneration projects are considered. At the federal level, the Clean Air Act Amendments of 1977 specifically authorize local governments to provide for the mitigation of the air quality impact of cogeneration projects by providing regional growth increments in the state implementation plan. This policy is carried through the California Air Resources Board (CARB) rules and the South Coast Air Management District (SCAQMD) Regulations.

Table 4. SUMMARY OF AIR POLLUTION RESTRICTIONS IN THE CSCAQMD*

(The numbers in parenthesis refer to the notes in Appendix I)

				Air Pollutants							
Equipment	Fuel	Capacity	Heat Input	NOX (1)	CO(2)	HC(3)	SO_x(10)	Particulates	Combust.(5) Contam.	Other	Cogen.
I. Boiler	Natural Gas	100,000 lbs steam per hour	133x10^6 BTU/hr	(13)	2,000 ppm	N.A.	N.A.	see #4	.23 gm/m^3 (0.1 gr/ft^3)	(7,9, 10,11)	No
II. Boiler	Natural Gas	100,000 lbs steam	133x10^6 BTU/hr	(13)	2,000 ppm	N.A.	N.A.	see #4	.23 gm/m^3 (0.1 gr/ft^3)	(6,7,9, 10,11)	Yes
III. Gas Turbine Generator	Natural Gas	3 MW	38.x10^6 BTU/hr	(6)	2,000	N.A.	N.A.	see #4	.23 gm/m^3	(6,8,9, 10,11)	Yes
		6 MW	76.x10^6	(13)							
		9 MW	113x10^6	(13)						(12)	

* California South Coast Air Quality Management District

The National Energy Act provides tax and regulatory incentives for cogeneration projects. A recent rule by the Federal Energy Regulatory Commission (FERC) exempts cogeneration projects of less than thirty megawatts from federal and state utility regulations. The FERC rule also orders utilities to buy back power from a cogenerator at full avoided cost and to supply the cogenerator with necessary power for peak periods. At the state level, California has recently passed legislation (Calif. Chapter 922 Statutes of 1979 - formerly AB524 effective January 1, 1980) which accomplishes the following:

1. Tells CARB to make an inventory of potential cogeneration projects through the utilities.

2. Tells CARB and the local air quality management districts to make estimates of emissions that would result from the cogeneration projects.

3. Instructs the CARB to make room in the California State Implementation Plan for these additional emissions.

The legislative intent of this bill is to remove air quality barriers to cogeneration projects. The CARB is currently requesting more funds in the proposed state budget in order to add sufficient staff to carry out these assignments.

At the regional level, SCAQMD has included several provisions in their regulations which exempt cogeneration projects or subject them to less stringent air quality restrictions. Among these are:

1. SCAQMD rule 475 exempts electric power generating projects of less than ten megawatts from the NO and combustion products limits which apply to larger sources. Additionally rule 475.1 (u) includes a broad exemption specifically for cogeneration projects.

2. SCAQMD rule 1304, allows the Executive Officer to exempt resource conservation and energy projects from the requirements of New Source Review provided BACT is used.

The Public Utilities Commission of the State of California in decision No. 91109 dated December 19, 1979, affirms its support of cogeneration in principal and specifically authorizes the utilities to:

1. Pay cogenerators the full avoided costs for purchased energy and for purchased capacity.

2. Provide for the simultaneous purchase by a cogenerator of its own electric requirements at utility average rates.

The foregoing examples indicate that cogeneration is receiving active encouragement as a matter of policy at all governmental levels.

5.2.3 Citrus Juice Quality Constraints

Citrus juices are sensitive to prolonged exposure to temperatures above 75°F. For this reason, it is unwise to circulate juice in an evaporator at elevated temperatures. The trend in citrus evaporator design has been to use multiple effects in series without recirculation so as to control the time-temperature exposure.

As citrus juices are concentrated, the viscosity increases, and the boiling point rises above that of water. These two factors hinder heat transfer, especially when dealing with small temperature differences between the heating medium and the juice. It is important to promote high velocities in the tubes to protect the concentrated juice from excessive time-temperature exposure. High viscosities and the 8°F boiling point rise at 65° Brix orange juice make it impractical to use mechanical vapor recompression on the finishing stages.

The time-temperature profile of a typical four effect "TASTE"[1] is given in Figure 9. The manufacture has further reduced the time at high temperatures by stacking effects on top of each other, thus eliminating the time in the separator, down leg, pump and pipe to the top of the next stage.

---

[1] "TASTE" is Gulf Machinery Company's trade name. It stands for "Thermally Accellerated, Short-Time Evaporator."

FIGURE 9

Typical Temperature Profile
of
The Four Effect, Seven Stage
"TASTE Evaporator
with Interstage Pre-Heater

Pre-heater	Temp. (°F)	Stage	Time (Sec.)	Effect
1	70 - 100		14	
2	100 - 120		11	
	120 - 106	1	6	IV
3	106 - 135		11	
4	135 - 160		8	
5	160 - 180		11	
6	180 - 206		11	
	206 - 190	2	22	I
	190 - 170	3	36	II
	170 - 145	4	30	III
	145 - 120	5	42	IV
a	120 - 130		62	
	130 - 120	6	28	IV
b	120 - 130		45	
	130 - 110	7	49	IV
Flash Cooler	110 - 60		13	
	Total		403	

The temperatures are not exactly the same from one evaporator to another. They also change as tubes foul, as the temperature of the condenser water changes, and if air leaks develop.

5.2.4 Economic Evaluation of Alternative Plant Configurations

A consistent method by which the alternative plant configurations will be evaluated in economic terms that are applicable to the citrus industry has been formulated. The alternative plant configurations are technically viable combinations of components that are synthesized according to the approach previously described in Section 3, and their performance and costs are determined under identical conditions and constraints. The alternative plant configurations will be evaluated in terms of investment payback time, internal rate of return, and net present value, which are calculated from the cost and revenue streams associated with their energy conserving subsystems. Those configurations that both save energy and show favorably in terms of the evaluations criteria will be further considered for implementation.

The economic evaluations of a specific plant configuration proceeds according to the following steps:

- Collection of data on capital cost, annual operation and maintenance cost, and other costs, receipts, and credits.
- Calculation of annual cash flow streams resulting from time-varying processing loads and energy prices over the system lifetime.
- Discounting of cash flow streams to time zero, i.e., the date of initial cash expenditure.
- Comparison of financial parameters with those of the baseline configuration.
- Calculation of investment payback period (PB), internal rate of return (IRR), and net present value (NPV).

The types of cost information required for economic evaluation are listed in Table 5. Information collection is a continuous effort whose schedule is dependent upon the needs of Task I.D., Synthesis. The annual cash flow for each of the alternative plant configurations is calculated from this cost and revenue information. The differential cash flow relative to the baseline configuration is the basis for computing the IRR, PB, and NPV for each alternative configuration. The economic and financial parameters required to compute the PB, IRR, and NPV have been derived from Sunkist's historical data.

The three criteria for evaluating the alternative systems are further discussed below:

Payback Period

This is the method widely used in the fruit processing industry. The payback period is the number of years it takes a firm to recover its investment.

$$\text{Payback (yrs)} = \frac{\text{Investment (\$)}}{\text{Net benefit rate (\$/yr.)}}$$

Although the Payback criterion is simple and easy to understand, it has serious drawbacks, among which are that it ignores cash flow beyond the payback period, and it ignores the time value of money.

Internal Rate of Return

This criterion is used widely in all industries, although not as extensively as the payback period. It is used in conjunction with payback period in the fruit processing industry. The internal rate of return (IRR) is the discount rate that equates the present value of the future net cash flow to the initial capital outlay. The investment proposal is viewed as profitable if the discount rate is greater than the cost of capital to the firm. The internal rate of return r^*, is calculated from:

$$\sum_{t=0}^{n} \frac{R_t - C_t}{(1 + r^*)^t} = 0$$

TABLE 5 Receipts and Disbursements for Energy Systems

CAPITAL COSTS	OPERATION AND MAINTENANCE COST	OTHER COSTS, RECEIPTS, CREDITS, ETC.
o Equipment Cost (including installation cost)	o Electricity Cost	o Standby capacity charges or receipts from Utility for serving as added capacity
o Equipment replacement cost	o Fuel cost[1]	o Receipts from sale of surplus electricity
	o Labor cost	o Credits - Investment tax - Energy
	o Operating supplies	
	o Insurance cost	
	o Taxes[2]	
	o Indirect Operating Cost	
	o Overhead	
	o Interest Cost	
	o Maintenance labor and material	
	o Other costs - Pollution permit cost	

---

[1] Natural gas or diesel

[2] Federal, state and local as applicable

where: R is the benefit stream corresponding to year t,
C_t is the cost stream corresponding to year t,
r^* is the discount rate or IRR, and n is the useful life of the system.

In comparing alternatives those with the higher rates of return are the most profitable.

Net Present Value

This method is seldom used in the fruit processing industry. It gives an indication of the viability of the investment but not the magnitude of the rate of return. The method involves finding the present value of the net cash flow resulting from an investment. If the net present value is positive, the project is profitable and systems with higher net present values are the most profitable. The net present value may be expressed as the

$$NPV = \sum_{t=0}^{n} \frac{R_t - C_t}{(1 + r)^t}$$

where R_t is the benefit stream corresponding to year t, C_t is the cost stream corresponding to year t, r is the discount rate, and n is the useful life of the system.

5.3 Work Completed - Task IB, Characterization of Basic Operations

In order to quantify the potential of energy savings in citrus fruit processing, each operation must be studied in some detail. The present methods of processing have evolved over the last half century as technology and the market place imposed their influences. Changes are continuing in the industry, and the high price of energy will certainly be one of the major factors in determining the course of events. This task, however, measures the amount and level of energy used in the citrus processing operations currently common to most plants operating in the United States.

5.3.1 Basic Citrus Processing Operations

Most citrus processing plants have the following basic operations:

a. Extraction of juice from fruit
b. Concentration of juice by evaporation
c. Recovery of citrus oils
d. Drying of peel and evaporation of peel liquors
e. Chilling, packaging and cold storage of citrus juice and concentrates

Figure 10, Flow Diagram of Typical Citrus Processing, illustrates these operations. Each of these steps in processing will be studied as shown in 5.3.3, Identification and Measurement of Energy Uses. From these measurements, it will be possible to synthesize a basic citrus plant from an energy use standpoint.

The Orange Products Division of Sunkist Growers, Inc., in Ontario, California, is the source of our characterization data. This plant is highly integrated, including the production of beverage bases, pectin, bioflavonoids, Perma-Stabil flavors and other products not considered basic to a typical citrus processing plant. This fact should be kept in mind when reading the following section.

5.3.2 Energy Consumption and Fruit Processed Vs. Time

Figure 11 shows the relationship between fruit processed and energy usage for Sunkist's Ontario plant by months during 1979. There seems to be a closer relationship between fuel used and fruit processed than between electrical demand and fruit processed.

The electrical load of 3 million KWH per month could be co-generated by using 45×10^9 BTU/mo. of fuel. This is well below the actual fuel being used. However, some fuel uses do not lend themselves to co-generation. Also, hourly data must be analyzed to fully evaluate the match between heat and electrical needs.

The daily usage of natural gas and electricity was measured for the month of March 1979 at the Orange Products Division in Ontario, California. This energy data and the amount of fruit processed are plotted in Figures 12 and 13. The natural gas is used primarily for generating steam in boilers and in

FIGURE 10

Flow Diagram of a Typical Citrus Processing Plant

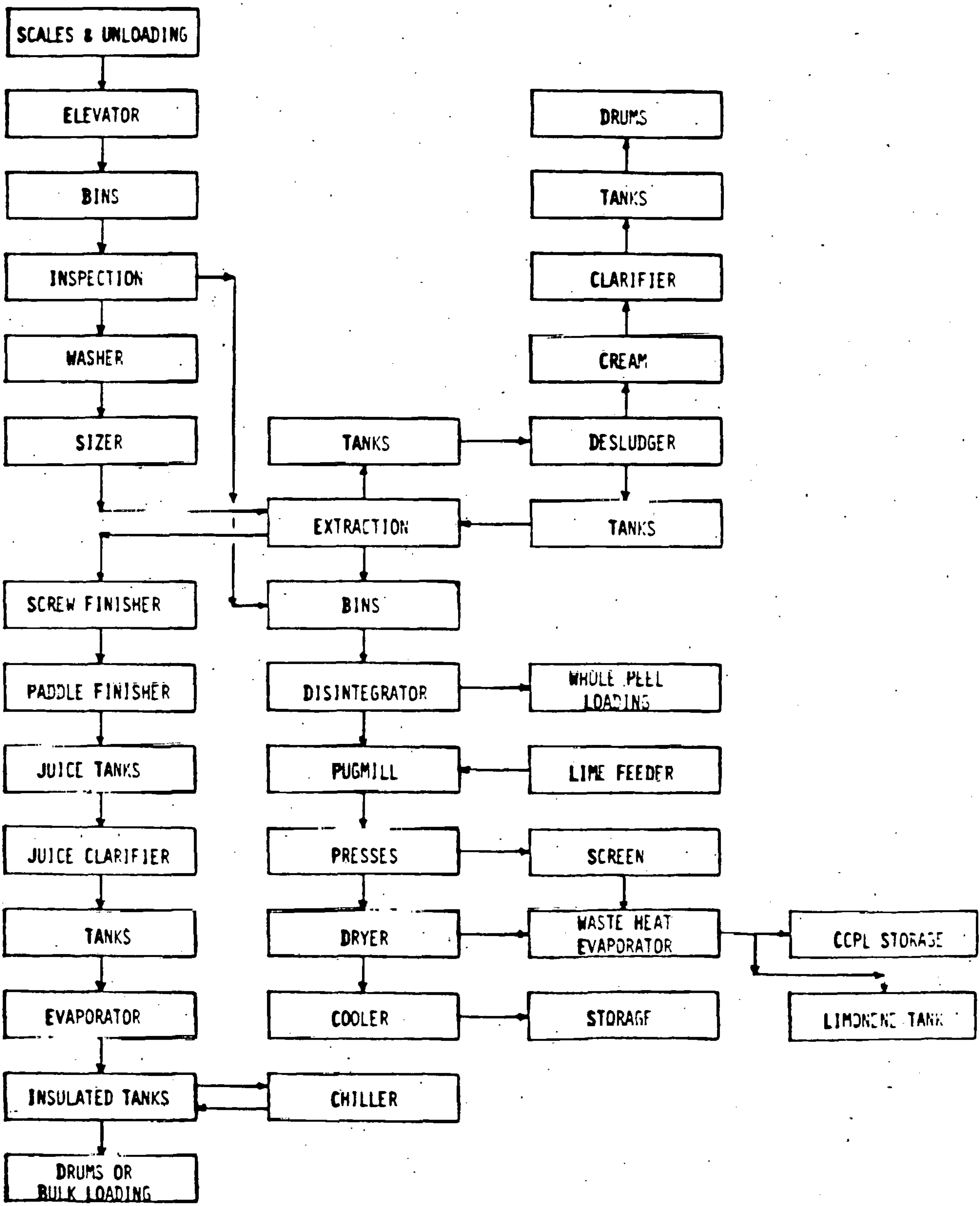
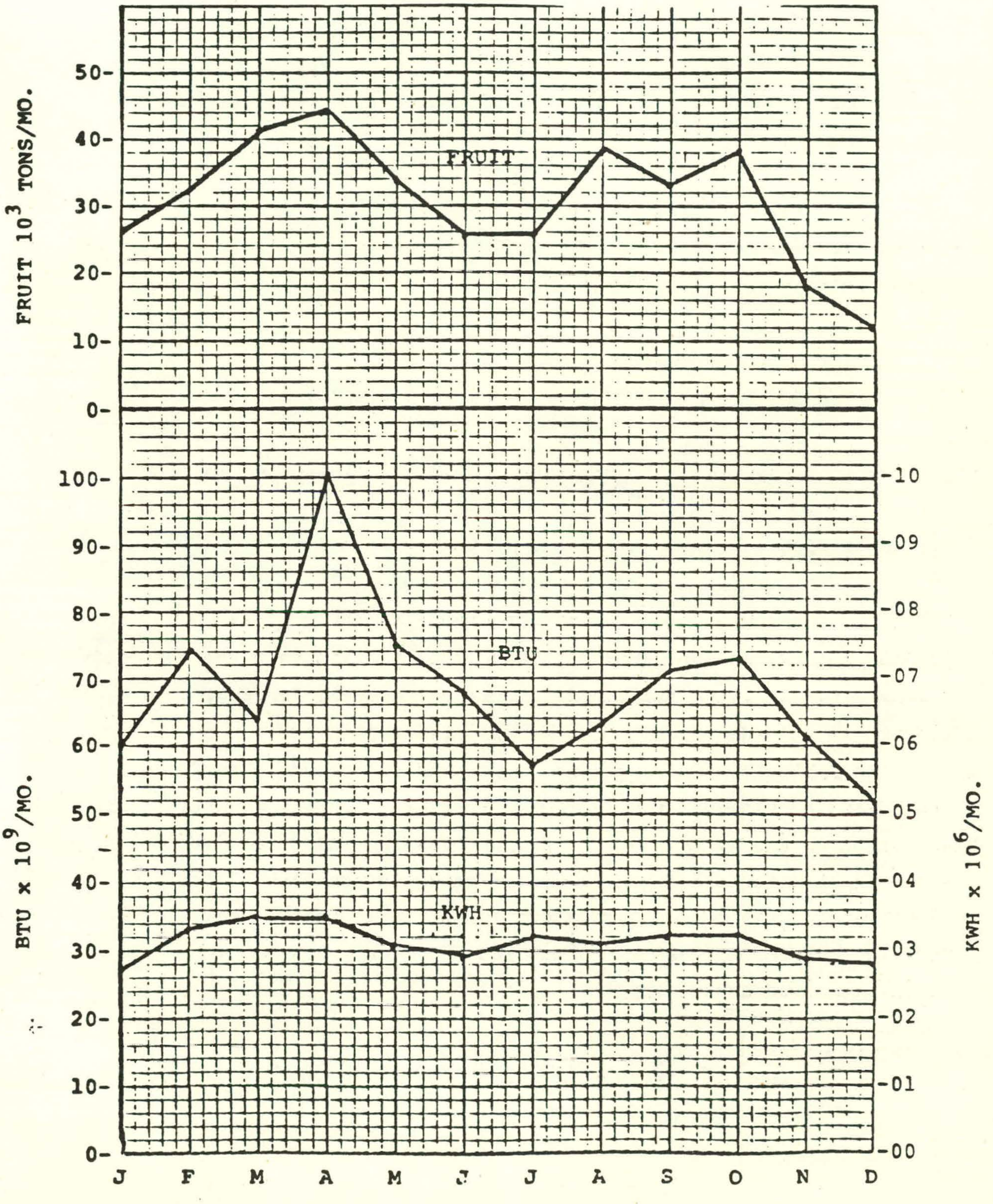


FIGURE 11. FRUIT PROCESSED & ENERGY USAGE

ORANGE PRODUCTS DIVISION
SUNKIST GROWERS, INC.



direct fired peel dryers. The electrical energy is used for the many motors throughout the plant. These motors operate refrigeration systems, belt and screw conveyors, blowers, pumps, pelletizers, etc. For this month, 83.6 KWHs of electrical power and 2.2×10^6 BTU of natural gas were used per ton of fruit processed.

The daily figures were used to determine the best straight line relationship between the amount of fruit processed and electrical energy, and between fruit processed and heat energy.

$$\text{Power, KWH/day} = 40\ F + 60{,}000$$

$$\text{Thermal Energy, BTU/day} = 1.8 \times 10^6 F + 525 \times 10^6$$

where F = Tons/day of fruit processed. This is illustrated in Figure 14.

5.3.3 Identification and Measurement of Energy Uses

The first operation studied at the Orange Products Division was the fruit unloading and extraction. There is no use of fuel in this process, but there are many motors driving belts, elevators, extractors, screens, screws, etc. The fruit is unloaded from trucks and is elevated to the top of storage bins. Later, the fruit is washed, graded, sized and extracted. The juice is screened and centifuged prior to concentration. Table 6, Identification and Measurement of Energy Uses at the Fruit Unloading and Juice Extraction, itemizes each motor and shows the power consumed compared to its rated load. On the average, the motors used about 70% of their rated load. The total power required for the 42 motors was 180 KW. The kilowatts were calculated from the measured amperes by this formula:

$$KW = \frac{\text{Amps} \times P.F_x 460 \times 1.732}{1000}$$

P.F. (Power Factor) was taken as 0.9.

SUNKIST GROWERS, INC., ORANGE PRODUCTS DIVISION
FRUIT & GAS CONSUMPTION PROFILES

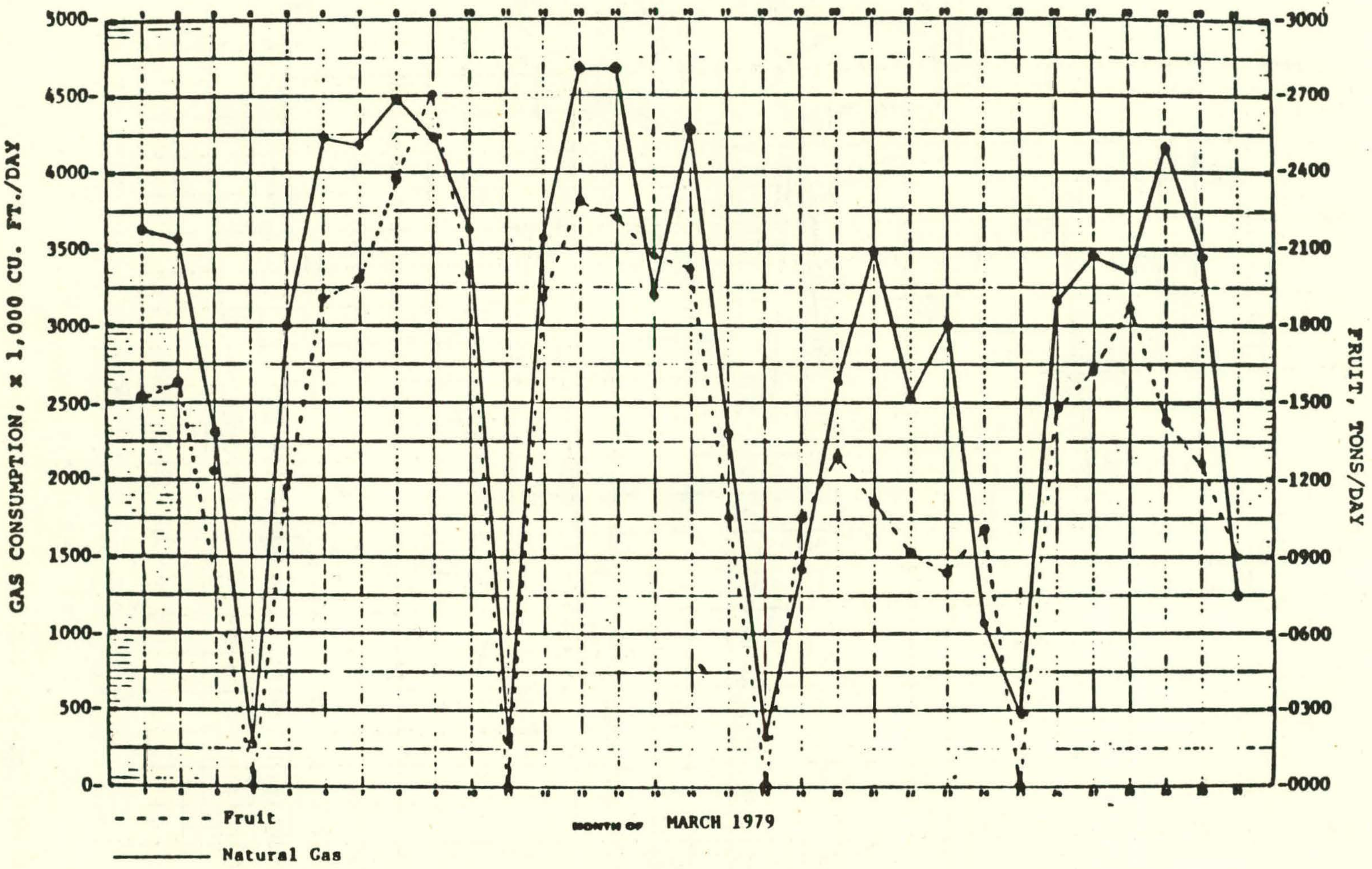
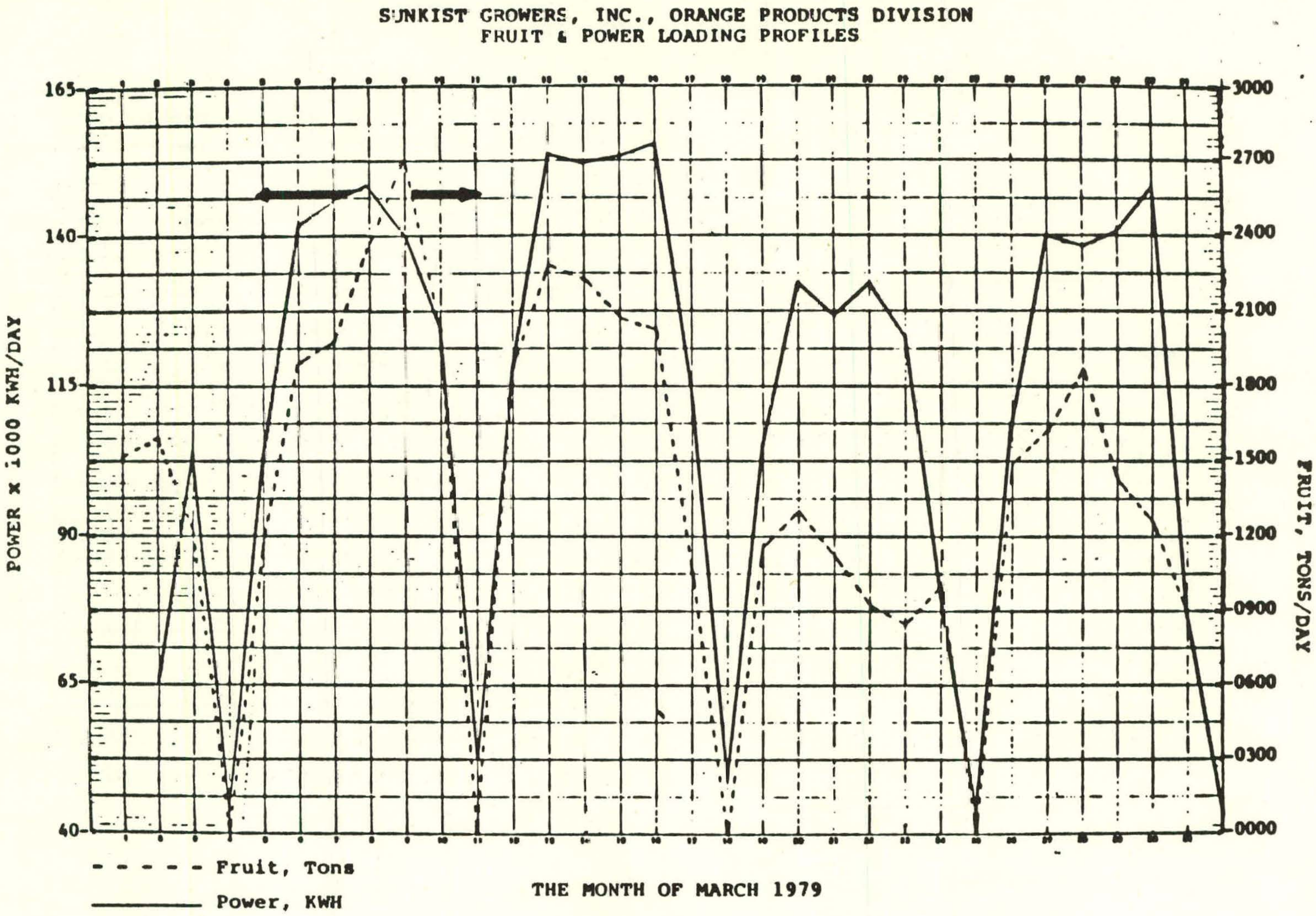


FIGURE 12



SUNKIST GROWERS, INC., ORANGE PRODUCTS DIVISION
FRUIT & POWER LOADING PROFILES

FIGURE 13.

FIGURE 14

ENERGY CONSUMPTION IN CITRUS PROCESSING

AT

SUNKIST, MARCH 1979

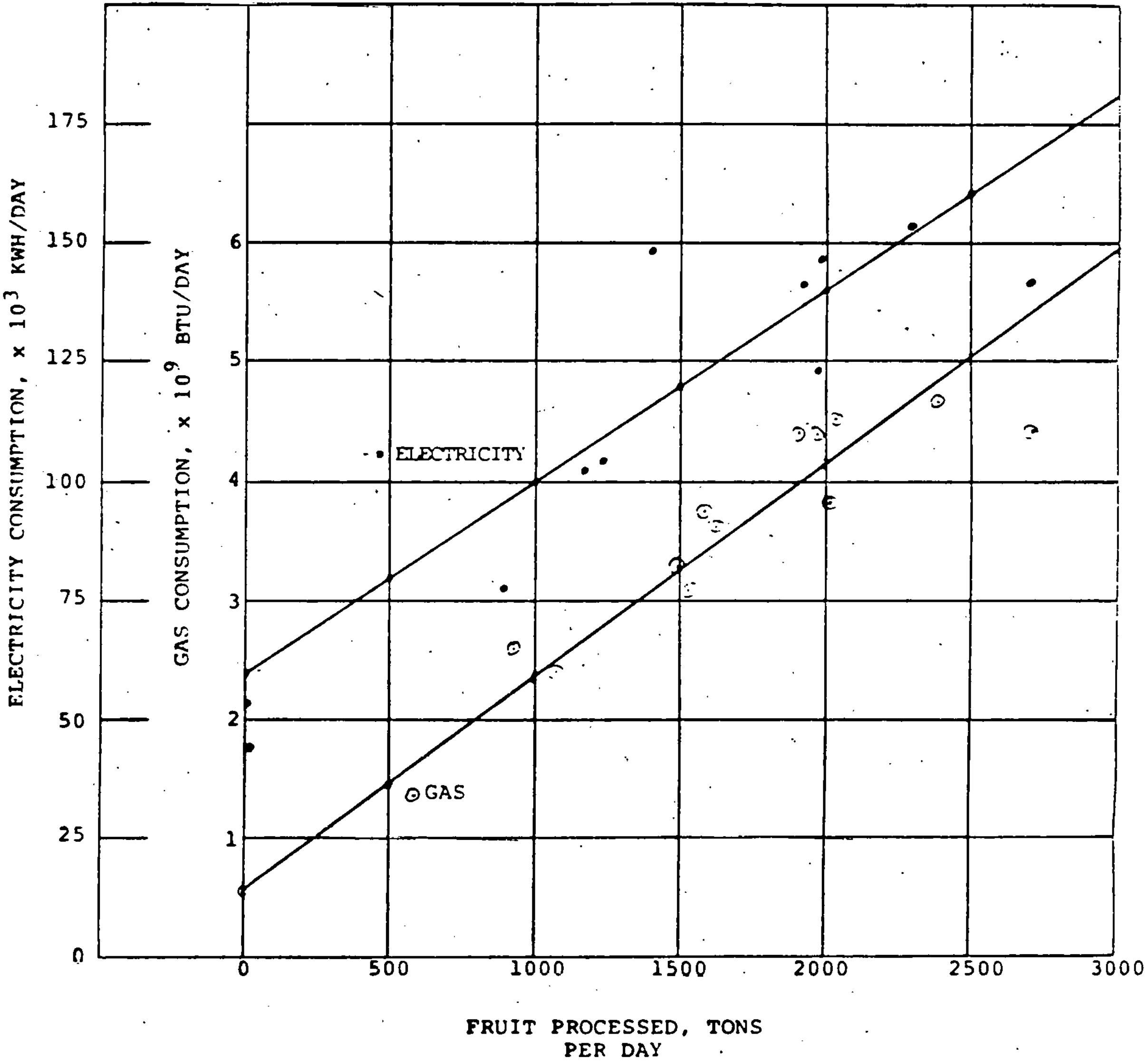


TABLE 6

Identification and Measurement of Energy Uses At the Fruit Unloading and Juice Extraction

MOTORS			LOAD CURRENTS, AMPERES					POWER CONSUMPT.	AVG. KWH	KWH $\bar{S}$ FRUIT-LOADING
NO.	HP	FLA	1	2	3	4	AVG	KWH/HR.	RATED KWH	KWH $\bar{C}$ FRUIT-LOADING
1	3	4.3	4.5	4.0*	4.4	4.3	4.3	3.08	1.0	0.91
2	3	4.3	2.5	2.2*	2.4	2.4	2.4	1.72	0.56	0.92
3	3	4.3	2.8	2.7*	3.8	3.8	3.3	2.37	0.72	0.77
4	1	1.8	1.0	1.0	1.0	1.0	1.0	0.72	0.56	1.0
5	7.5	10.8	8.5	8.0*	8.5	8.0	8.2	5.88	0.76	0.96
6	7.5	10.5	7.0	6.5*	7.5	7.0	7.0	5.02	0.67	0.9
7	5	7	4.6	4.6	4.8		4.6	3.3	0.66	
8	3	4.5	4.2*	4.0	4.3	4.6	4.3	3.08	0.95	0.98
9	3	4.3	2.4*	2.5	2.5	2.4	2.4	1.72	0.56	0.96
10	3	4.3	3.1*	3.2		3.4	3.2	2.29	0.74	0.94
11	1.5	2.2	1 *	1		1.0	1.0	0.72	0.45	1.0
12	7.5	10	9 *	7.0		7.0	7.6	10.9	0.76	1.28
14	1	1.8	1.6	1.2	1.2	1.2	1.3	0.93	0.72	
15	1.5	2.3	1.7	1.6		1.6	1.6	1.15	0.70	
16	3	4.8	4.1	4.2		4.1	4.1	2.94	0.85	
17	3	4.8	3.8	3.8		3.8	3.8	2.72	0.79	
18	2	3.7	1.8	1.7		1.8	1.8	1.29	0.49	
19	2	3.7	2.3	2.2		2.4	2.3	1.65	0.62	
20	2	3.4	3.4	3.0		2.8	3.0	2.15	0.88	
21	3	4.8	3.2	3.0		2.8	3.0	2.15	0.62	
22	15	20	9 *	9.5		8.5	9.0	6.45	0.46	1.0
23	1.5	2.3	2.1*	2.2		2.1	2.1	1.51	0.91	0.95
24	3	4.5	3.1*	3.4		3.1	3.2	2.29	0.71	0.97
25	5	7	6	6		5.5	5.8	54.06	0.83	
26	5	7	4.6*	4.5		4.2	4.4	3.15	0.63	1.04
27	1/3	0.65	0.5	0.5		0.5	0.5	0.35	0.77	
28	3	4.6	3.2	3.2		3.0	3.1	4.44	0.67	
30	10	13.5	10 *	9		9.5	9.5	27.25	0.70	1.06
34	3	4.5	2.2	2.2		2.2	2.2	1.57	0.49	
35	7.5	9.5	8.5	8.0		8.0	8.1	5.81	0.85	
37	5	7	4 *	3.8		3.8	3.8	2.72	0.54	1.05
38	40	50	11 *	12.5		12.0	11.9	8.53	-	
40	1	1.5	1.4*	1.8		1.8	1.6	1.15	1.07	0.78
41	1.5	2.3	1.6	1.6		1.6	1.6	1.15	0.70	
42	5	7.3	6	6		6.2	6.1	4.37	0.83	
									$\bar{x}$ = 0.69	$\bar{x}$ = 0.98

** $\bar{S}$ = without
$\bar{C}$ = with

* No Fruit Loading

Figure 15, Fruit Unloading and Juice Extraction Flow Diagram shows the flow through this operation and the names of each piece of motorized equipment. Figure 16 is an energy accounting diagram showing the kilowatts for each part of the operation when running at 36 tons of fruit per hour. However, when running empty, the power is only about 2 percent less than when handling the normal amount of fruit.

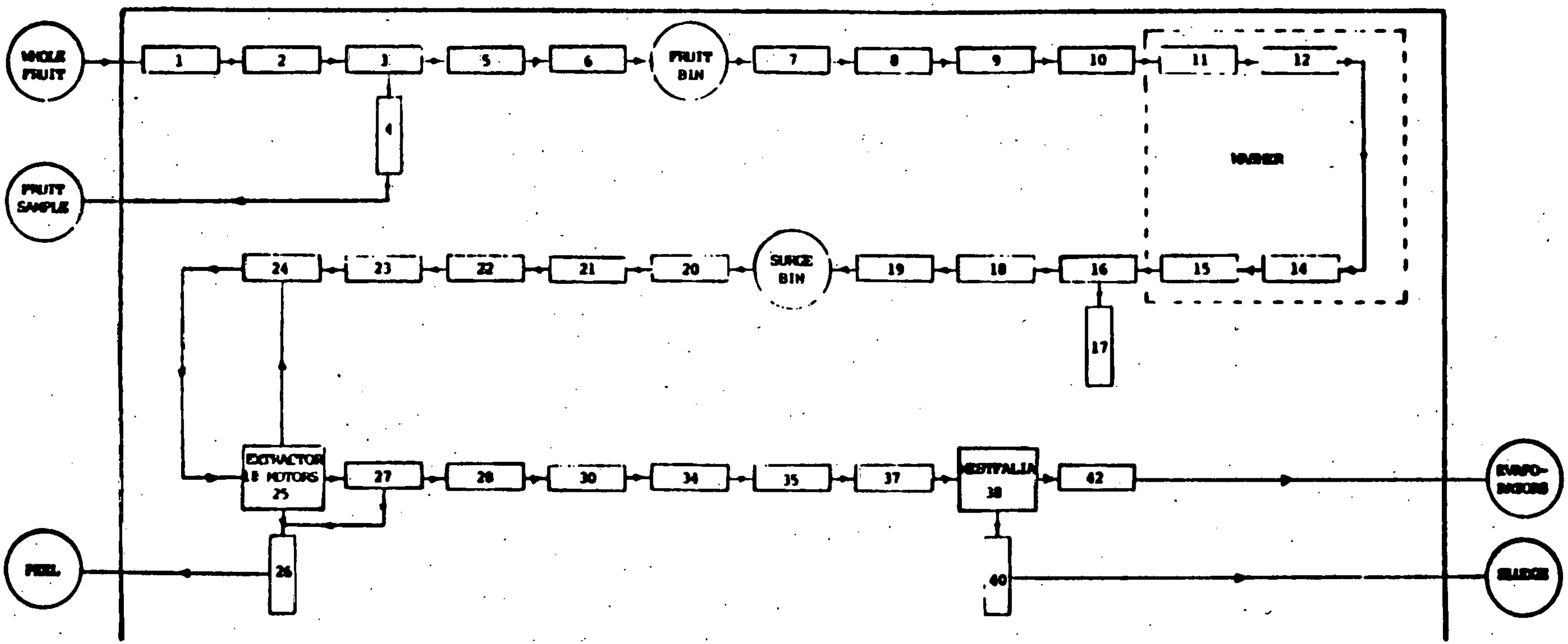
5.3.4 Energy Balance for a Typical Citrus Juice Evaporator

The citrus processing industry has progressed beyond the single or double effect evaporators. It has been cost effective to install four and five effect evaporators using 212^{o}F. steam as a heat source, and cooling tower water as a heat sink at the condenser. The motive steam required to evaporate 40,000 pounds per hour is shown in Figure 17, for evaporators of 4-8 effects. The steam economy, pounds evaporation per pound of motive steam, is also shown. This clearly shows the incentive to install additional effects.

The heat and material balance calculations for a multi-effect evaporator requires a trial and error procedure. The logic for this is illustrated in Figure 18. It is necessary to predetermine the temperature of each step in the juice flow.

As an example, a detailed heat and material balance has been made for a forward feed, five effect, 40,000 pounds per hour evaporator with inter-stage pre-heaters. The data and calculations are shown in Figures 19a and 19b. The motive steam turns out to be 9,142 lbs/hr giving a steam economy ratio of 4.38.

FIGURE 15
Fruit Unloading and Juice Extraction Flow Diagram



1. No. Scale Unloading Belt
2. No. Scale Roller Elevator
3. No. Scale High Elevator
4. No. Scale Sampler
5. E.W.N. Top Belt
6. West Bin Top Belt
7. No. 1 Drain Out Belt
8. So. 48 inch Belt
9. So. 48 inch Rollers
10. So. 48 Inch Washer Feed Belt
11. Line No. 4 - Washer Paddle
12. Line No. 4 - Washer Recircularting Pump
14. Line No. 4 - Washer Elevator
15. Line No. 4 - Washer Roller
16. Line No. 4 - Grading Belt
18. Line No. 4 - Fruit Lift
19. Line No. 4 - E/W Belt
20. Line No. 4 - Surge Bin Belt
21. Line No. 4 - Roller Conveyor
22. Line No. 4 - East Sizer Belt
23. Line No. 4 - Sizer Roller
24. Line No. 4 - Extractor Feed/Return Belt
25. Extractor No. 6
26. So. Refuse Screw
27. Line No. 4 - Peel Rec. Rollers
28. Line No. 4 - Juice Pump
30. Finisher No. 6 Bank No. 1
34. Refuse Pulp Screw
35. Secondary Finisher Juice Pump
37. Westfalia Feed Pump
38. Westfalia
40. Westfalia Sludge Pump
41. Return Elevator

FIGURE 16
Energy Accounting Diagram for Fruit Unloading and Juice Extraction

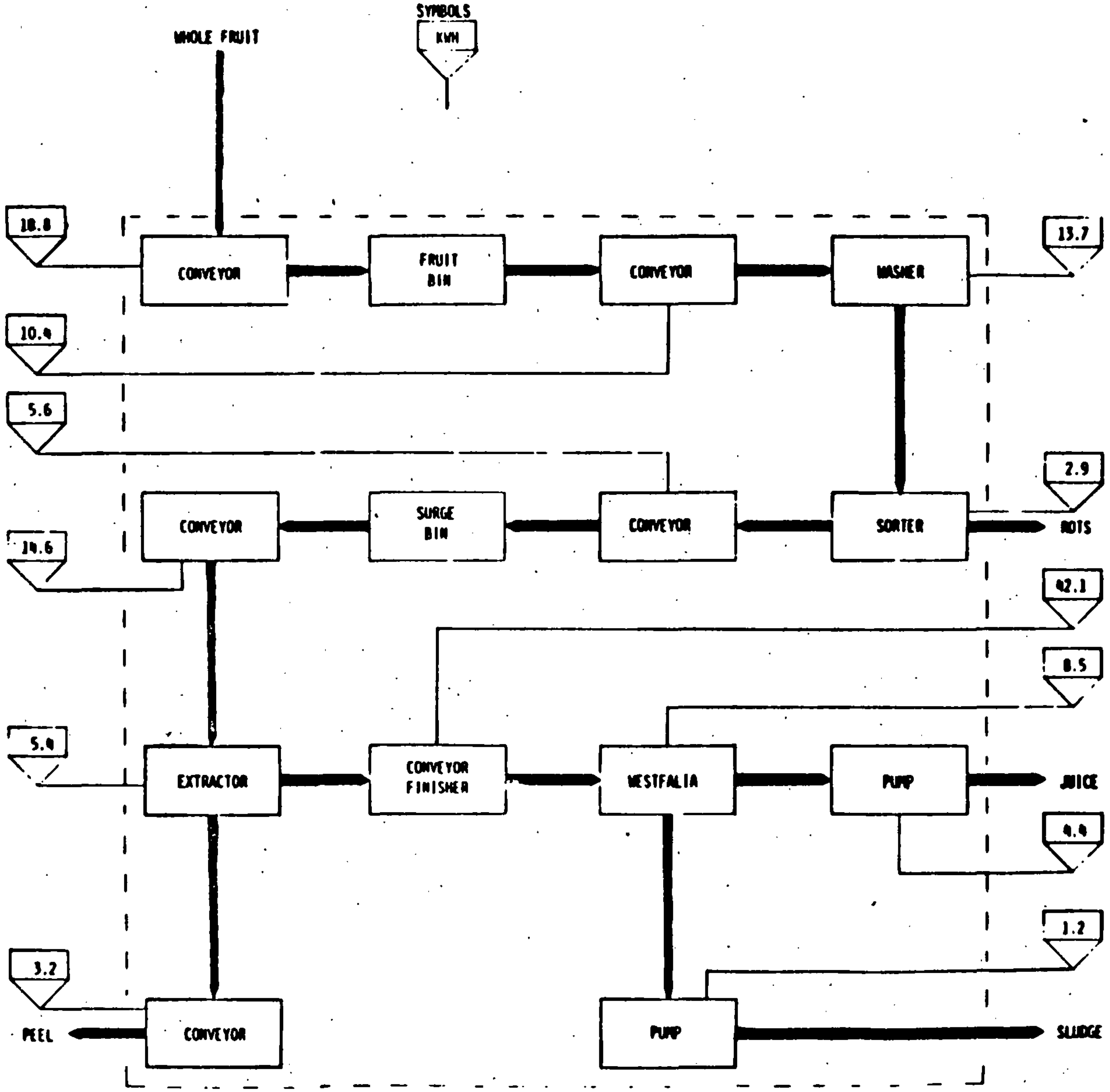


FIGURE 17

MULTI-EFFECT EVAPORATOR - FORWARD FLOW, 40,000 LB/HR EVAPORATION

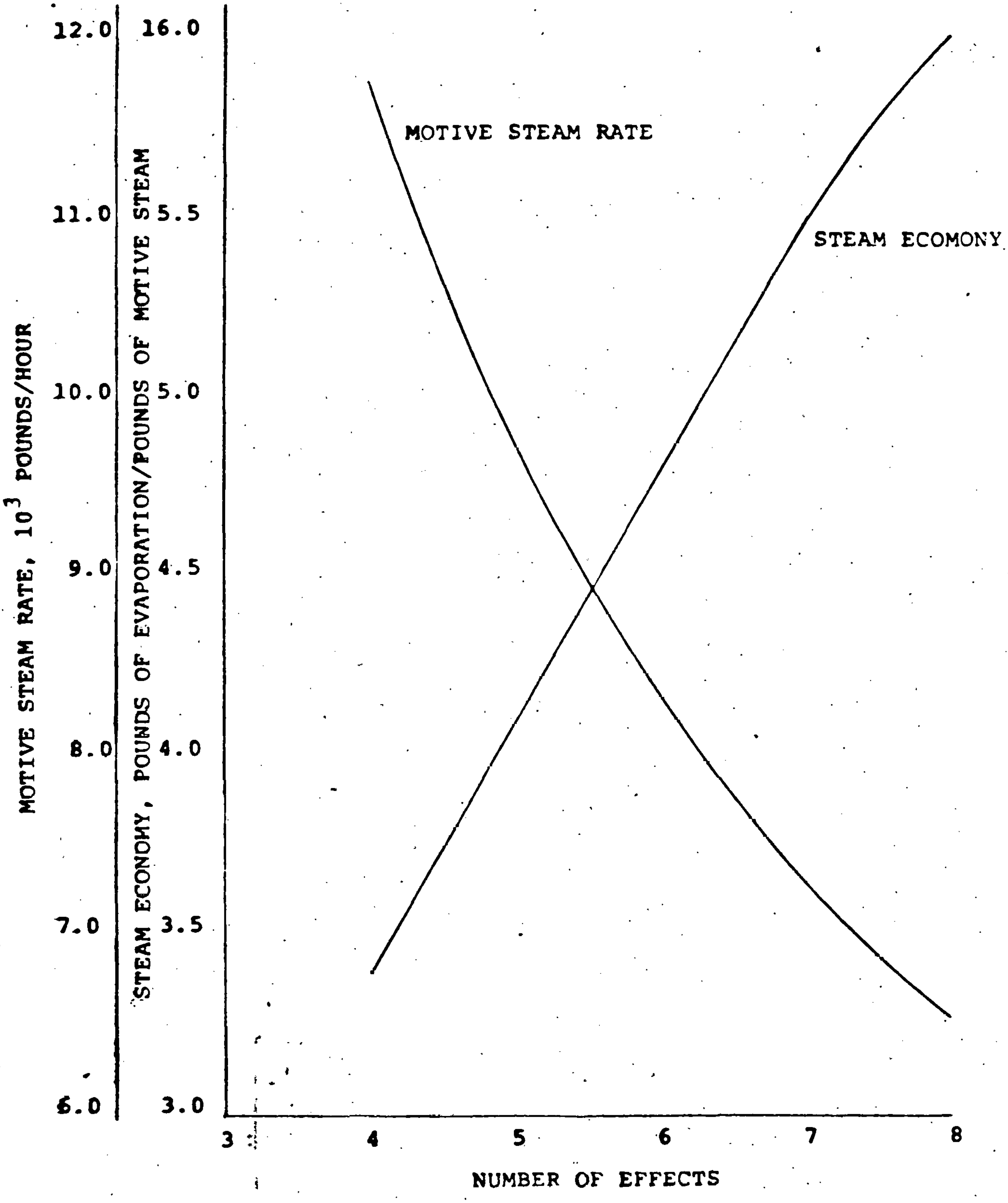


FIGURE 18

LOGIC DIAGRAM FOR HEAT AND MATERIAL BALANCES

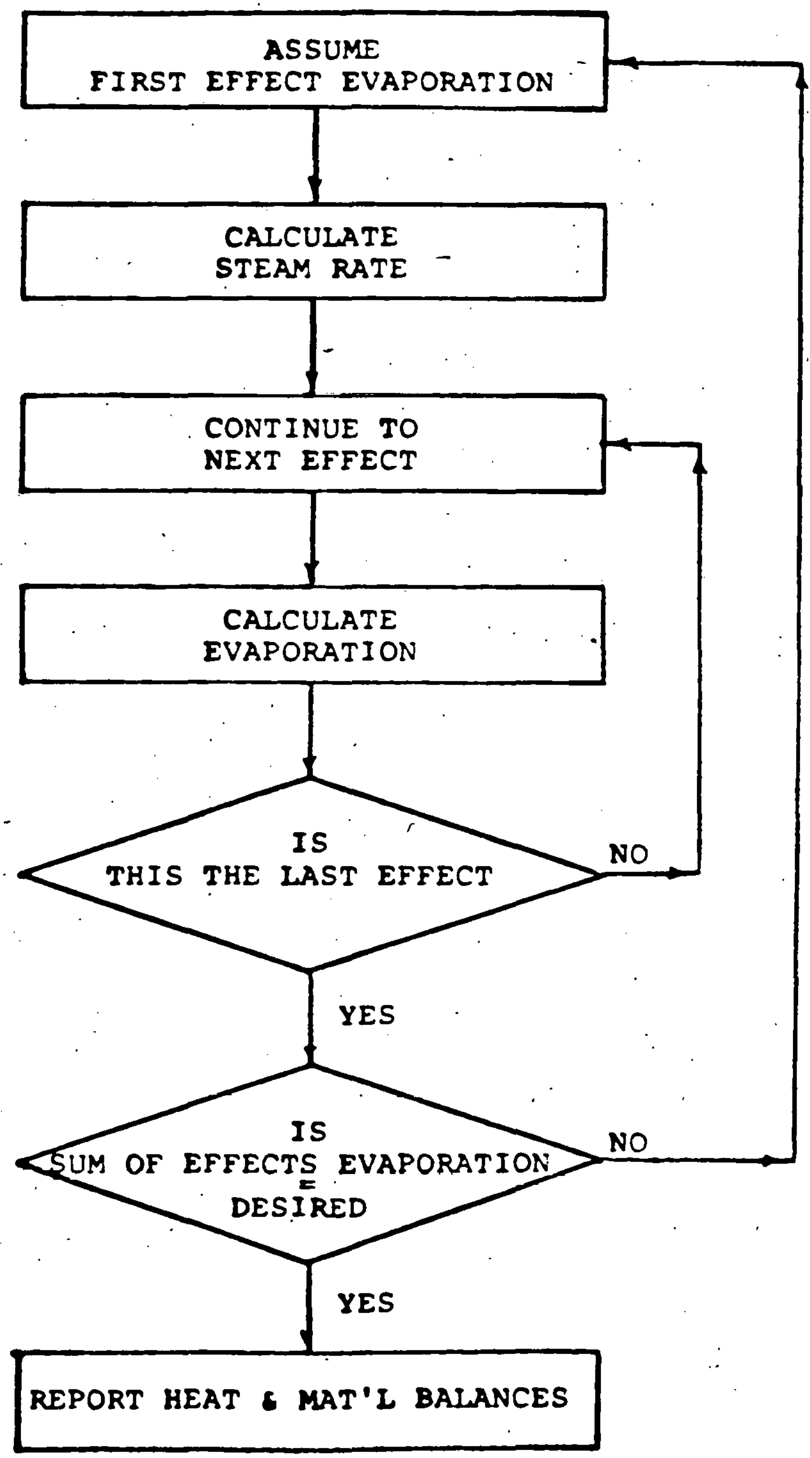
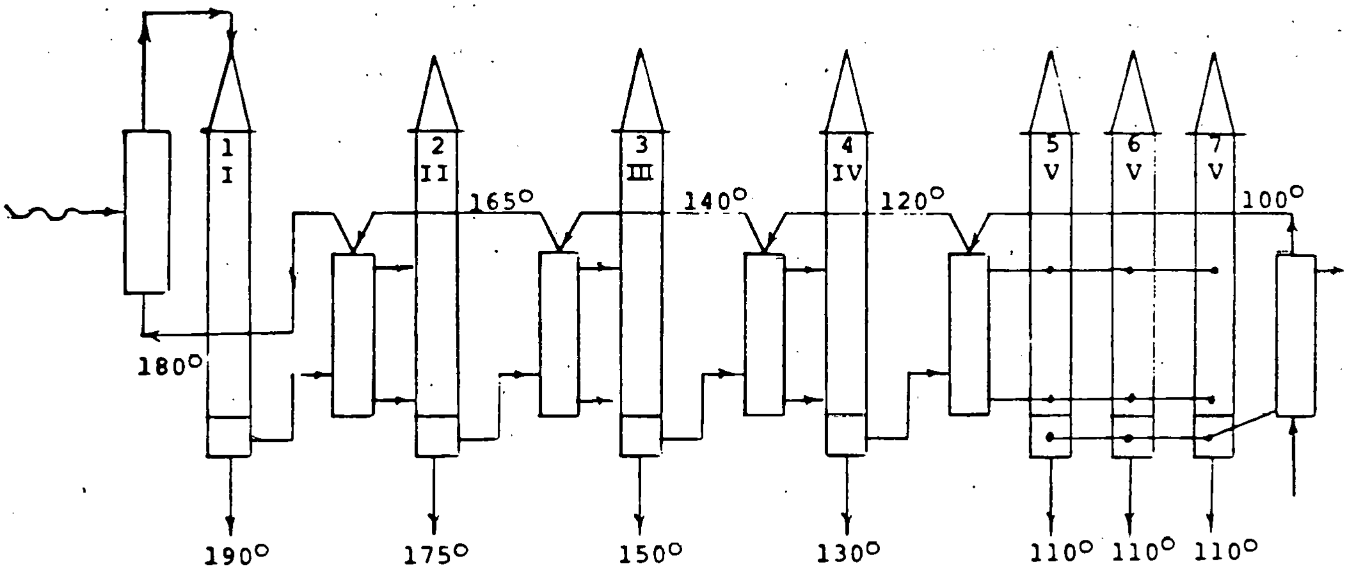


FIGURE 19A

MATERIAL & ENERGY BALANCE OF TASTE EVAPORATOR
5 EFFECTS, 7 STAGES WITH PRE-HEATERS



Temp. °F	ENTHALPY Liq.	ENTHALPY Vapor
70	38.04	--
100	67.94	1105.2
110	77.94	1109.5
120	87.92	1113.7
130	97.90	1117.9
140	107.89	1122
150	117.89	1126.1
165	132.89	1132.2
175	142.91	1136.2
180	147.92	1138.1
190	157.95	1142.0
212	180.07	1150.4

FIGURE 19B

ENERGY BALANCE

Effects	Heat In	Heat Out
<u>FIRST</u>		
Steam	1150.4 S_o	8575 x 1142
Feed Juice	48,872 x 147.92 x 0.92	40,297 x 157.95 x 0.9
Condensate		180.07 x S_o
	S_o =	9142 lbs/hr
<u>SECOND</u>		
Vapors	8575 x 1142	E_2 x 1136.2
Conc. Juice	40,297 x 157.95 x 0.9	(40,297 - E_2) x 142.91 x 0.875
Feed Juice	48,872 x 132.89 x 0.92	48,872 x 147.92 x 0.92
	E_2 =	8358
	Conc. Juice =	31,939
<u>THIRD</u>		
Vapors	8358 x 1136.2	E_3 x 1126.1
Conc. Juice	31,939 x 142.91 x 0.875	(31,939 - E_3) x 117.89 x 0.84
Feed Juice	48,872 x 107.89 x 0.92	48,872 x 132.89 x 0.92
Condensate	8575 x 157.95	16,933 x 142.91
	E_3 =	7922
	Conc. Juice =	24,017
<u>FOURTH</u>		
Vapors	7922 x 1126.1	E_4 x 1117.9
Conc. Juice	24,017 x 117.89 x 0.84	(24,017 - E_4) x 97.90 x 0.77
Feed Juice	48,872 x 87.92 x 0.92	48,872 x 107.89 x 0.92
Condensate	16,933 x 142.91	24,855 x 117.89
	E_4 =	7746
	Conc. Juice =	16,271

FIGURE 19B (cont'd.)

Effects	Heat In	Heat Out
FIFTH		
Vapors	7746 x 1117.9	E_5 x 1109.5
Conc. Juice	16,271 x 97.9 x 0.77	(16,271 - E_5) x 77.94 x 0.67
Feed Juice	48,872 x 67.94 x 0.92	48,872 x 87.92 x 0.92
Condensate	24,855 x 117.89	32,601 x 97.90
	E_5 =	7446
	Conc. Juice =	8825
	Sum of Evaporation =	40,047
	Steam Economy =	40,047 ÷ 9142 = 4.38

5.3.5 Future Work in Task IB, Characterization

Plans are being developed to identify and measure electrical and thermal energy consumption in the following processes:

Juice Evaporation
Press Liquor Concentration
Citrus Oil Recovery
Pasteurization
Packaging
Refrigeration & Cold Storage
Drum Thawing (Conc. Juice)

A data logger will be used to record temperatures and perhaps pressures and flow rates. Individual motor loads will be measured with a portable ammeter. Steam flow will be measured by weighing condensate or by flow meter. Juice flows will be measured by tank level vs. time. Soluble solids levels will be measured by refractometer.

The plant electrical and natural gas consumption will be recorded over a weeks time in short time intervals to determine the best size co-generation unit. The plant production level will also be measured during the same period. The above measurement will use the data accumulator ACT-PAK Model 5008 and a special computer printout of electrical service from Southern California Edison Company.

The above data will be used to simulate a typical citrus processing plant of average capacity for the purpose of trying out the several alternative systems for energy conservation.

5.4 WORK COMPLETED - TASK I.C, THERMODYNAMIC ANALYSIS

5.4.1 Heat Pumps

Heat pumps transmit thermal energy from a heat source at temperature, T_c to a heat sink at a higher temperature, T_h , as shown in Figure 20. Heat pumps can be used in citrus processing to upgrade heat of evaporator condensate, in the temperature range of 100-160° F, to more useful heat in the range of 185-212°F.

Every pound of oranges processed produces about 0.9 lb. of condensate from evaporating and peel drying operations. Perhaps 5-10% of the condensate can be used as wash water and another 10-25% as boiler make-up water. The rest, 65-75%, is disposed of along with its energy content. A heat pump is a way of recouping some of this lost heat.

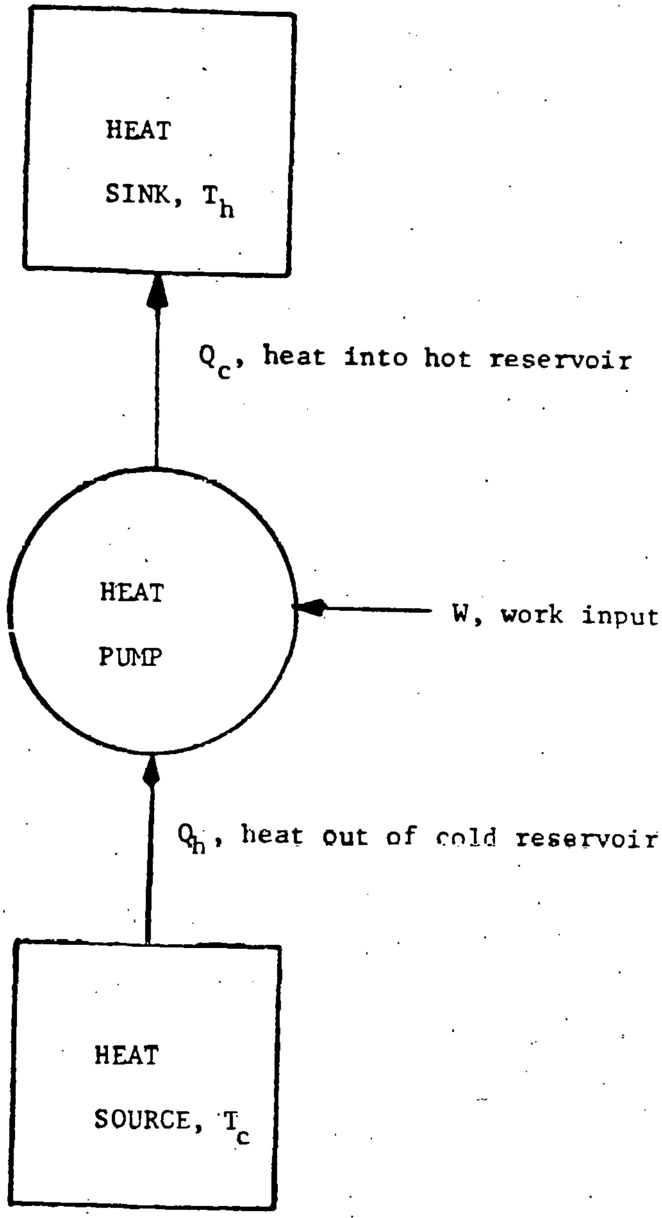


FIGURE 20 SCHEMATIC OF HEAT PUMP

The use of heat pumps in this manner depends in part upon the amount of work which must be supplied to transfer a unit of heat. This is gauged by a figure of merit called the coeffient of performance (COP), defined as the ratio of heat transfered into the heat sink to the work required to drive the heat pump.

$$\mathrm{COP} = \frac{Q_h}{W} \tag{1}$$

where Q_h = heat transferred to sink or hot reservoir
W = work input into heat pump

The heat pump with the higher COP is the more efficient.

B. THEORETICAL PERFORMANCE

For ideal heat pumps, a relation is derived for COP in terms of the temperature of the heat sink, T_h, and heat source, T_c. An energy balance about the heat pump in Fig. 20 reveals the work input to be the difference of the heat transferred to the heat sink and the heat drawn from the heat source.

$$W = Q_h - Q_c \tag{2}$$

where Q_c = heat drawn from heat source of cold reservoir

substituting Eq. 2 in Eq. 1 yields the interim result.

$$\mathrm{COP} = \frac{1}{1 - Q_c/Q_h} \tag{3}$$

This equation is further simplified by applying the following assumption used in formulating the Carnot temperature scale.

$$\frac{Q_c}{Q_h} = \frac{T_c}{T_h} \tag{4}$$

The final result becomes

$$COP = \frac{1}{1 - T_c/T_h} \tag{5}$$

where T_c = temperature of heat source (^oK)

T_h = temperature of heat sink (^oK)

Notice that since T_c is always less than T_h, COP is greater than or equal to one. For example, the COP is 12.8 for an ideal heat pump which uses 135^oF (330^oK) condensate as heat source and produces 185^oF (358^oK) water. COP values for real heat pumps will be a factor of three or four less than ideal values due to heat and work losses to the atmosphere.

C. ACTUAL PERFORMANCE OF A CLOSED LOOP ORGANIC RANKINE CYCLE

The object of this section is to derive an expression for the COP of actual devices by taking heat and work losses into account. Before the derivation begins, a brief discussion of closed-loop organic Rankine cycle heat pumps is in order.

The device consists of a compressor and accompanying drive, two heat exchangers (one interfacing with the heat sink and the other with the heat source) and an expansion valve (Fig. 21). A two-phase mixture of refrigerant at a temperature slightly below that of the heat source enters the heat exchanger pictured at the bottom of Fig. 21 (cold side heat exchanger). Heat is transferred and the liquid portion of the refrigerant competely vaporizes to a gas. Subsequently, this gas is reduced in volume by the compressor, thus increasing its temperature to a value slightly above that of the heat sink. Hot gas from the compressor enters the remaining heat exchanger where heat flows to the heat sink, thus causing the refreigerant to condense to liquid. This liquid then passes through an expansion valve where the pressure drops abruptly and some of the liquid

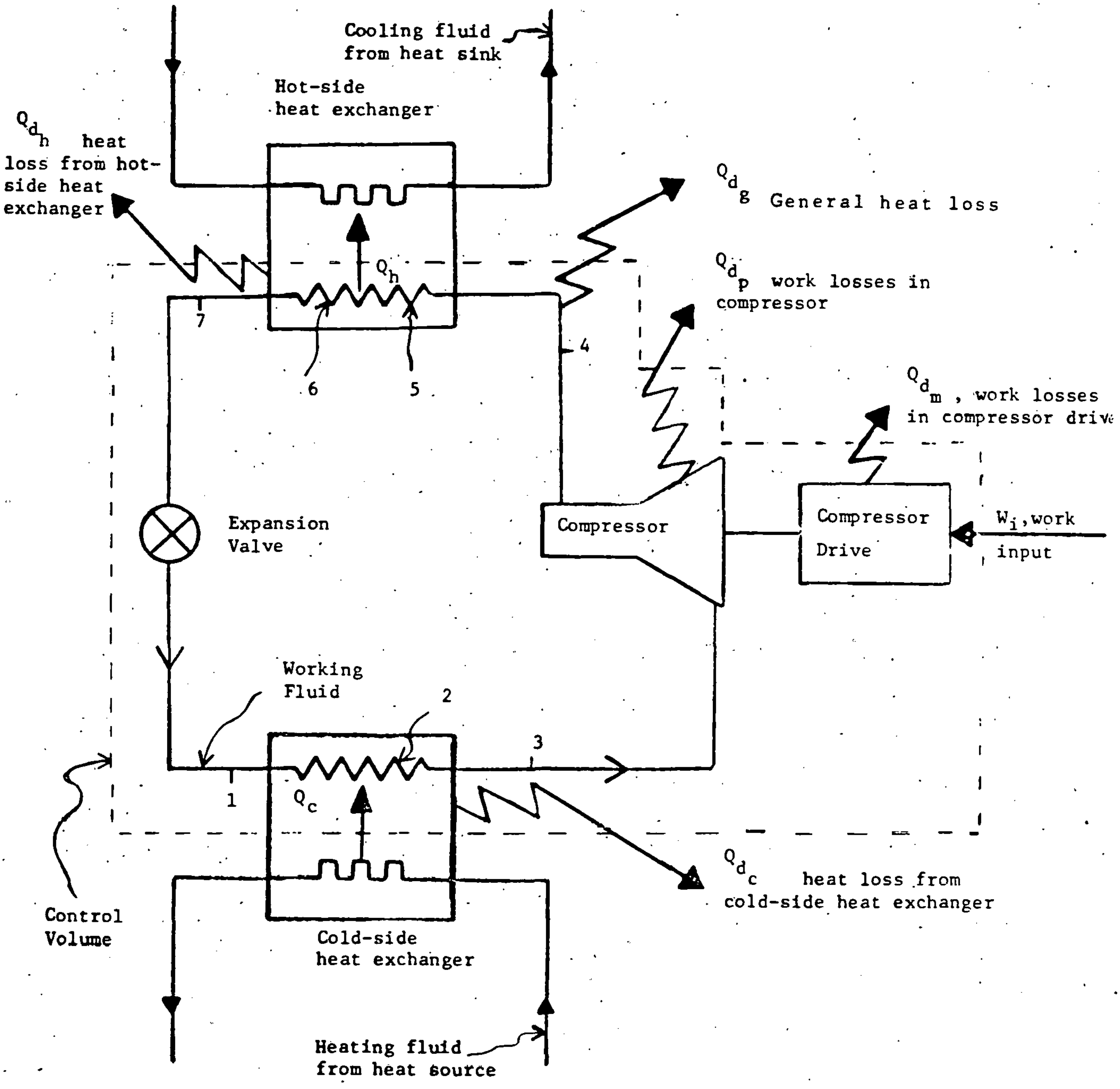


FIGURE 21 SCHEMATIC OF COMMERCIAL HEAT PUMP WITH ENERGY FLOWS IN AND OUT OF CONTROL VOLUME

flashes to form a two-phase mixture, and the cycle begins agains. Figure 22 shows a T-S diagram listing each of the steps mentioned above.

The derivation of the COP begins with Eq. 1

$$\mathrm{COP} = \frac{Q_h}{W_i} \tag{1}$$

This time, the work imput W_i is determined according to an energy balance about the control valume in Figure 21.

$$W_i = Q_h - Q_c + Q_{d_m} + Q_{d_p} + Q_{d_g} + Q_{d_h} + Q_{d_c} \tag{6}$$

where Q_d = Heat dissipated to surroundings

Q_{d_m} = compressor drive

Q_{d_p} = compressor

Q_{d_g} = heat loss from piping and ancillary components

Q_{d_h} = hot heat exchanger (heat sink)

Q_{d_c} = cold heat exchanger (heat source)

Each loss term will be specified further. The work lost in the compressor drive Q_{d_m}, is a function of the motor and mechanical drive efficiency and the work input.

$$Q_{d_m} = (1 - \eta_m)W_i \tag{7}$$

η_m = motor and mechanical drive efficiency

W_i - work input into motor

The work lost in the compressor is likewise a function of the compressor efficiency, η_c and the work input, $W_i - Q_{d_m}$

$$Q_{d_p} = (1 - \eta_c)(W_i - Q_{d_m}) \tag{8}$$

substituting Eq. 7 in Eq. 8 yields,

$$Q_{d_p} = \eta_m W_i (1 - \eta_c) \tag{9}$$

1-2 Isothermal evaporation in cold-side heat exchanger
2-3 Superheat of refrigerant, cold-side heat exchanger
3-4 Compression
4-5 Desuperheat in hot-side heat exchanger
5-6 Isothermal condensation, hot-side heat exchanger
6-7 Liquid cooling, hot-side heat exchanger
7-1 Expansion in expansion valve

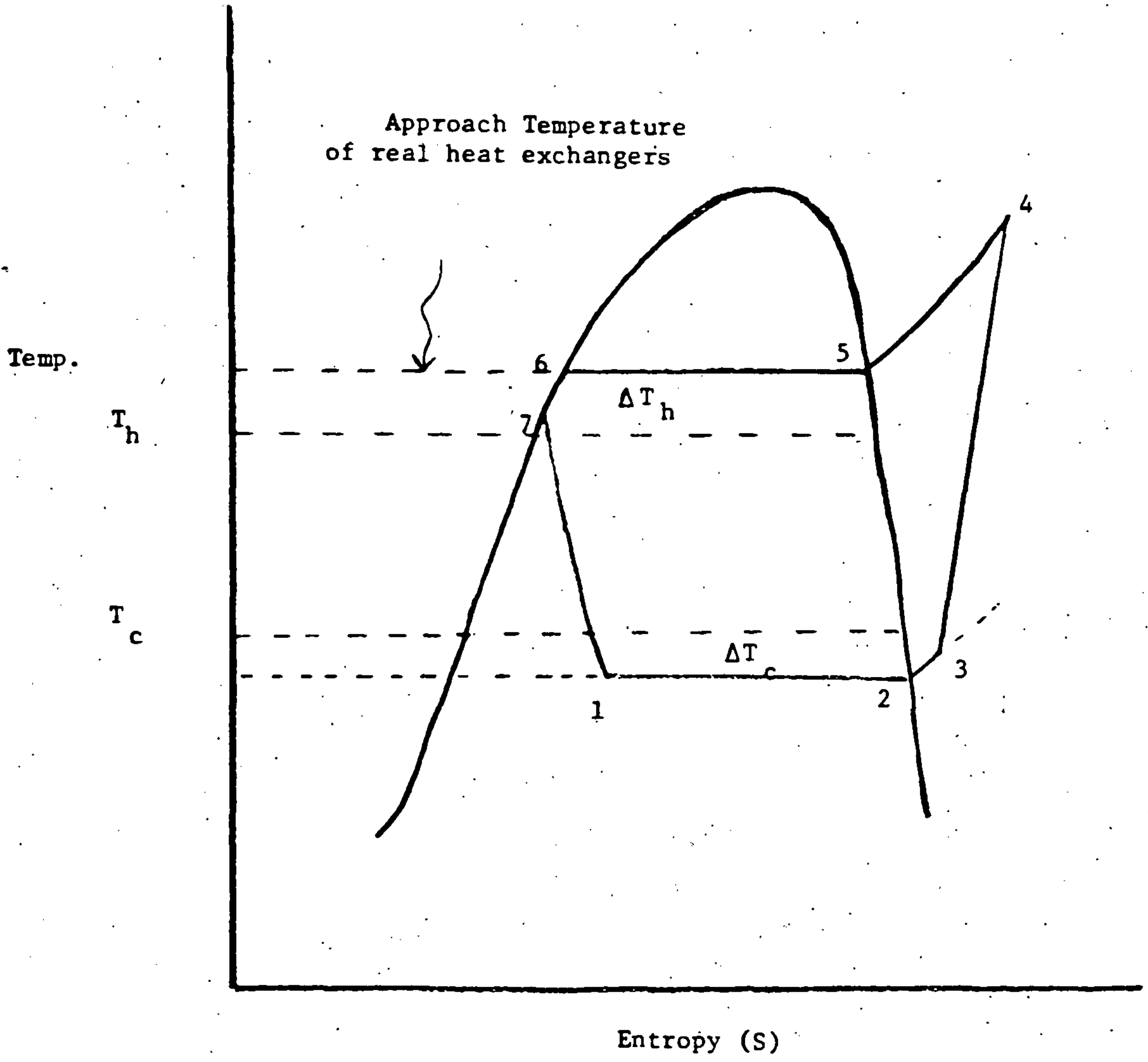


FIGURE 22 T-S DIAGRAM FOR RANKINE CYCLE HEAT PUMP

The terms Q_{d_g}, miscellaneous heat loss and Q_{d_h}, heat loss from hot side heat exchanger are both expressed in terms of Q_h.

$$Q_{d_g} = M\,Q_h \tag{10}$$

$$Q_{d_h} = H\,Q_h \tag{11}$$

Both M and H are fractions less than unity and each must be determined experimentally.

The heat lost from the cold-side heat exchanger, Q_{d_c} is expressed in terms of Q_c,

$$Q_{d_c} = C\,Q_c \tag{12}$$

where once again C is a fraction less than one which must be determined experimentally.

Substituting Equations 7, 9, 10, 11 and 12 into Equation 6 and solving for W_i yields

$$W_i = \frac{Q_h - Q_c + (M + H)\,Q_h + CQ_c}{\eta_m\,\eta_c} \tag{13}$$

Using this expression in Equation 1 gives an interim result for COP.

$$\text{COP} = \frac{\eta_m\,\eta_c}{(1 - Q/_{c}Q_h) + M + H + C\,(Q_c/Q_k)} \tag{14}$$

Again, the Carnot relation, Eq. 4, may be applied with a modification. T_h' and T_c' are actually the refrigerant temperatures and are related to the heat sink and source temperatures by the relations

(15)

$$T_h' = T_h + \Delta T_h$$

$$T_c' = T_c - \Delta T_c \tag{15}$$

where ΔT = finite temperature differences need to transfer heat in heat exchangers.

Substituting these equations into Equation 4 and the result into Equation 14 yields the final equaton for COP.

$$\mathrm{COP} = \frac{\eta_m \cdot \eta_c}{\left\{1 - \left(\frac{T_c - \Delta T_c}{T_h + \Delta T_h}\right)\right\} + M + H + C\left(\frac{T_c - \Delta T_c}{T_h + \Delta T_h}\right)} \tag{16}$$

η_m = work output of compressor motor/work input
η_c = work output of compressor/work input
T_c = temperature of heat source or cold reservoir
T_h = temperature of heat sink or hot reservoir
ΔT = finite temperature difference between the reservoir and working fluid temperatures
ΔT_h = ΔT for hot side heat exchanger
ΔT_c = ΔT cold side heat exchanger
M = Q_{d_g}/Q_h
Q_{d_g} = miscellaneous heat lost to atmosphere from piping and other components
Q_h = heat transferred to heat sink
H = Q_{d_c}/Q_c
Q_{d_h} = heat lost to atmosphere from hot (heat sink) heat exchanger
C = $Q_{d_c}\ Q_c$
Q_{d_c} = heat loss from cold side (heat source) heat exchanger
Q_c = heat transferred from heat source

Notice that as all loses go to zero, i.e.,

$M \longrightarrow 0$
$H \longrightarrow 0$
$C \longrightarrow 0$
$\eta_m \longrightarrow 1$
$\eta_c \longrightarrow 1$

$$T \longrightarrow 0,$$

the actual COP above reduces to the theoretical COP (Eq. 5) as would be expected.

D. VERIFICATION

This section compares the output of Eq. 16 with that of commercially available Rankine-cycle heat pump. Assume an industry wishes to produce hot water at $212_{o}F$ ($373^{o}K$) using a heat pump.

The heat source varies in temperature from $100^{o}F$ ($311^{o}K$) to $140^{o}F$ ($358^{o}K$). The heat pump's performance charcteristics are assumed to be those listed in Table 7. The predicted COP compared to that of a two-stage commercial heat pump (Westinghouse Templifier) as shown in Fig. 23. Maximum error is about 5%.

TABLE 7: LIST OF ASSUMPTIONS FOR HEAT PUMP PERFORMANCE PARAMETERS

Parameter	Value	Reference
η_m	0.92	Ekroth
η_c	0.73	Ekroth
ΔT_h	16.5^oK	Reay
ΔT_c	8.50^oK	Reay
M	0.01	
H	0.01	
C	0.01	

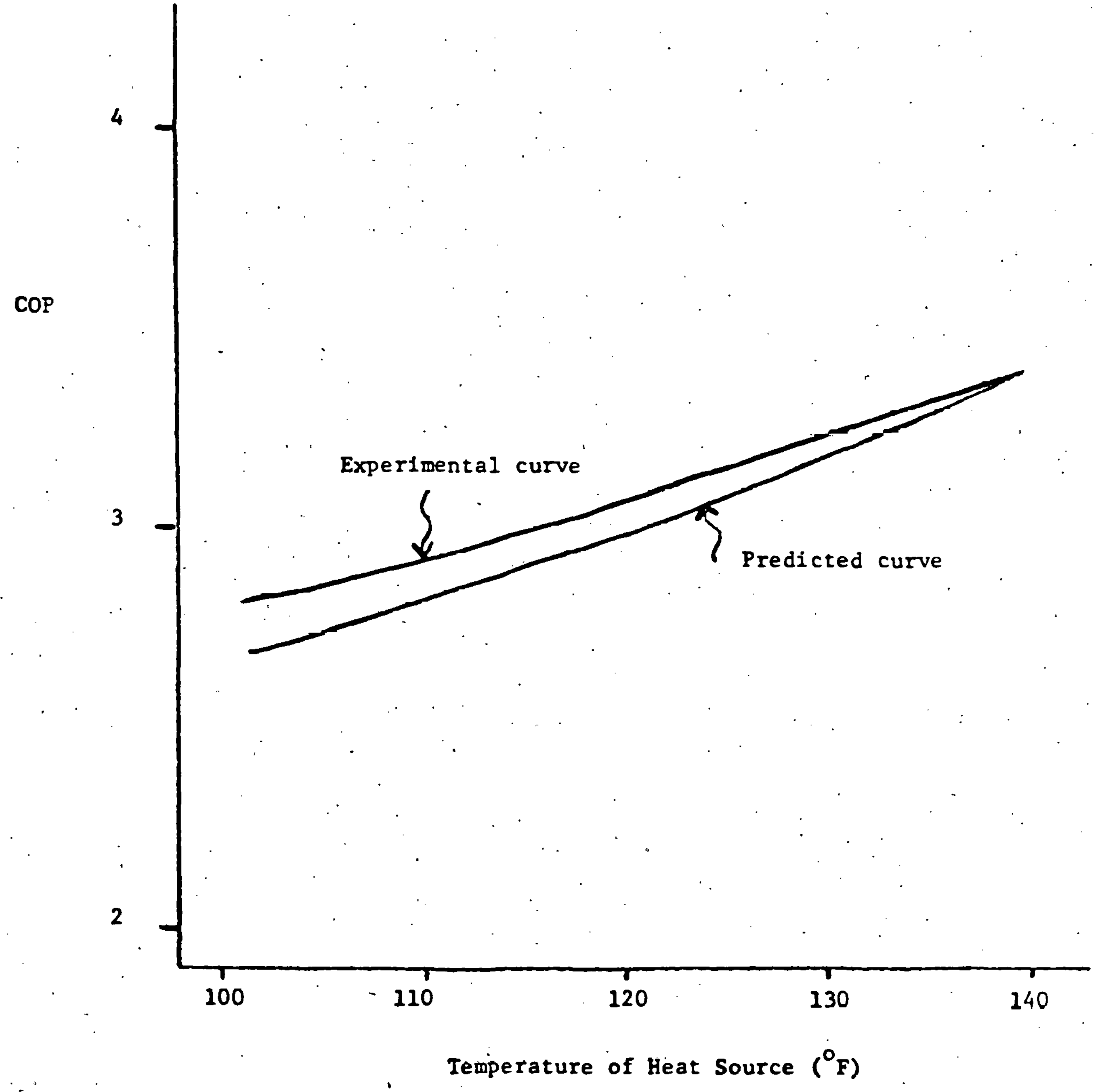


FIGURE 23 COMPARISON OF PREDICTED AND EXPERIMENTAL VALUES FOR COP

5.4.2 THERMAL EVAPORATOR

A. INTRODUCTION

The purpose of this section is to derive an expression for X_e, the mass concentration of juice exiting an effect, in terms of measurable energy and mass flows. In order to simplify the derivation, imagine the evaporator effect to be split into two separate units, A and B, as shown in Figure 24.

The function of Unit A is to separate water from incoming juice, and the function of Unit B is to supply heat needed for the separation process. In Unit A, a mass flow rate of juice, J_i, enters with mass concentration X_i. This juice receives heat at a rate, Q_J, and boils. The water vapor evolved in the boiling process is separated and sent onward at a mass flow rate of V_e. This vapor will serve either as a heat source for the next effect or will be condensed and disposed of. The juice that remains after boiling is more concentrated than when it entered and is sent onward at a mass flow of J_e and a concentration X_e. This juice will either receive further concentration in subsequent effects or will have a high enough concentration to serve as product.

As mentioned previously, Unit B supplies the rate of heat flow, Q_J, that drives separation processes in Unit A. Unit B receives heat input from both steam and hot condensate. Steam enters at a mass flow rate of S and is condensed. Condensate enters at mass flow rate of C_i, a portion flashes and is condensed. The major portion of the heat exiting Unit B is transferred to Unit A; some of the heat, Q_P is dedicated to preheating incoming juice; another portion, Q_L, is lost to the atmosphere; and the rest leaves as internal energy in the exiting condensate at a rate, (C_e) (h_{C_e}) where h_{C_e} is the specific enthalpy.

B. DERIVATION

With the evaporator effect split as shown above, control volumes can be easily drawn about both units. Mass and energy balances performed on a control volume about Unit A results in the following equations:

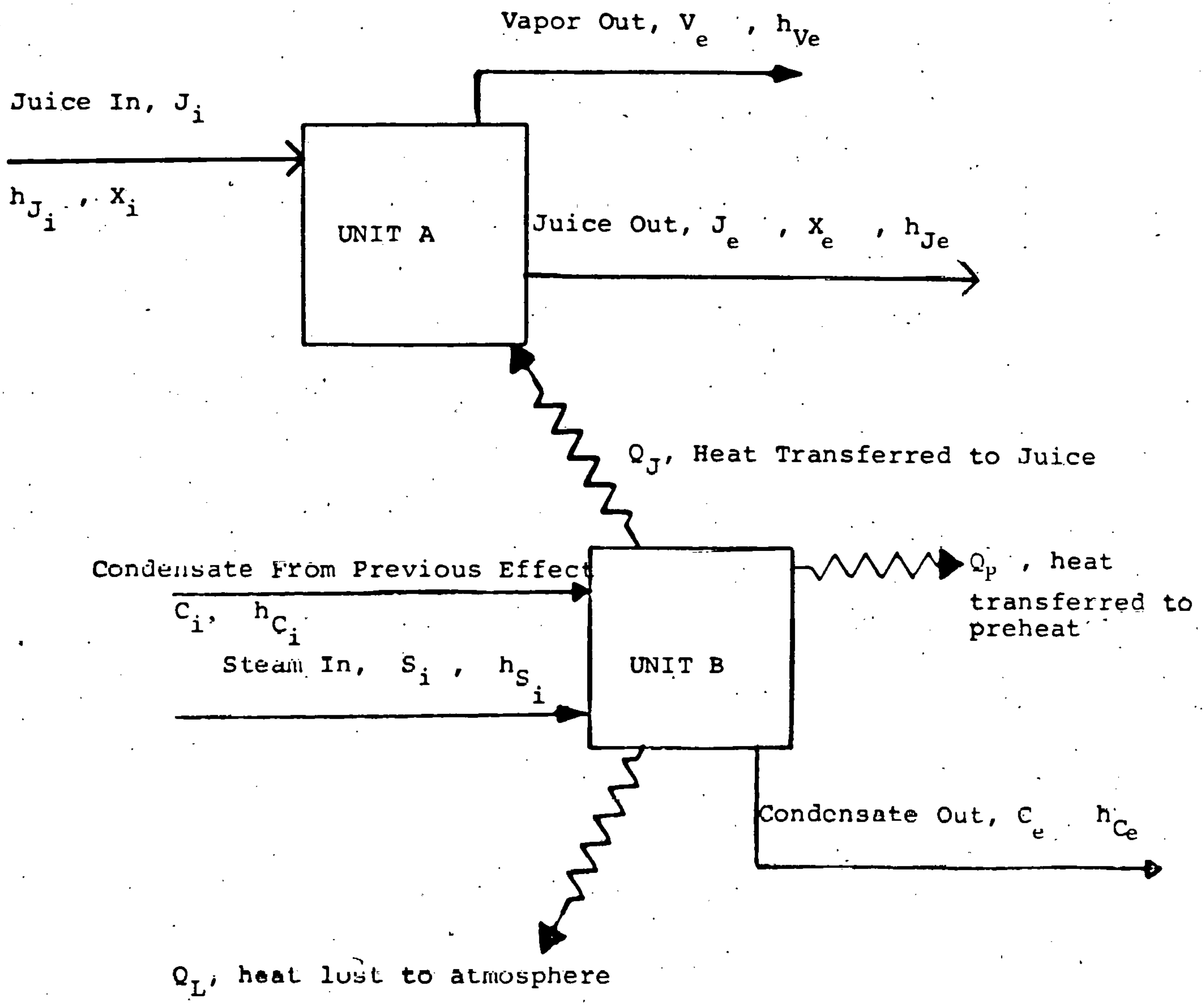


FIGURE 24. SCHEMATIC OF EVAPORATOR

$$V_e = J_i - J_e \tag{1}$$

where

V_e = mass flow rate of vapor
J_i = mass flow rate of juice in
J_e = mass flow rate of juice out

$$J_i = h_{J_i} + Q_J = V_e h_{V_e} + J_e h_{J_e} \tag{2}$$

where

h = specific enthalpy
h_{J_i} = h of juice in
h_{V_e} = h of juice out
Q_J = rate of heat flow from Unit B to Unit A

Equations 1 and 2 can be combined and rearranged to yield

$$J_e = \frac{J_i \ (h_{V_e} - h_{V_i}) - Q_J}{h_{V_e} - h_{J_e}} \tag{3}$$

Assume no solids are vaporized then,

$$X_i \ J_i = X_e \ J_e$$

or

$$J_e = \frac{X_i}{X_e} \ J_i \tag{4}$$

Substituting (4) into (3) results in the equation,

$$X_e = \frac{X_i \ J_i \ (h_{V_e} + h_{J_e})}{J_i \ (h_{V_e} - h_{J_i}) \ Q_J} \tag{5}$$

Mass and energy balances on a control volume about Unit B allows further specification of the term Q_J. A mass balance yields:

$$C_i = C_e - S_i \tag{6}$$

where

C_i = mass flow of condensate in
C_e = mass flow of condensate out
S_i = mass flow of steam in

An energy balance yields:

$$C_i \, h_{C_i} + S_i \, h_{S_i} = C_e \, h_{C_e} + Q_P + Q_J \tag{7}$$

where

h_{C_i} = h of condensate in
h_{S_i} = h of steam in
h_{C_e} = h of condensate out
Q_P = rate of flow to preheat
Q_L = rate of heat last to atmosphere

Substitutions Eq. (6) into (7) and solving for Q_L reveals:

$$Q_J = C_e \, (h_{C_i} - h_{C_e}) + S_i \, (h_{S_i} - h_{C_i}) - Q_P - Q_L \tag{8}$$

Substituting Eq. (8) into Eq. (5) gives the final result

$$X_e = \frac{X_i \, J_i \, (h_{V_e} - h_{J_e})}{J_i \, (h_{V_e} - h_{J_i}) - C_e \, (h_{C_i} - h_{C_e}) - S_i \, (h_{S_i} - h_{C_i}) + Q_P + Q_L} \tag{9}$$

X = mass of solids in juice/mass of juice
X_e = X out of effect
X_i = X into effect
J = mass flow rate of juice
J_i = J into effect
J_e = J out of effect
C = mass flow rate of condensate
C_e = C out of effect
S = mass flow rate of steam or vapor in
h = specific enthalpy
h_{V_i} = h of vapor in
h_{J_i} = h of juice in
h_{V_e} = h of vapor out of effect
h_{J_e} = h of juice out of effect
h_{C_i} = h of concentrate in
h_{C_e} = h of condensate out
h_{S_i} = h of steam in
Q_P = heat transfer to preheat
Q_L = heat lost to atmosphere

This equation will be used as a tool for determining if an evaporator effect is operating up to design specifications. In such an effort, Q_L would be the unknown and all other parameters must be measured. Research has indicated (Ref.1) that Q_L is of the order of two percent of the steam heat input, $S_i\ h_{S_i}$. If Q_L is determined to be much greater than this value, then the vendor should be contacted to rectify the situation. The second way this equation will be used is as a starting point for a much larger model which will encompass the complete analysis for an evaporator system of up to seven effects.

C. VERIFICATION

Equation 9 is verified using data presented by Chen for a five effect, seven stage evaporator. Table 8 shows experimental data used to compute X_e. THis computed value is compared to the experimental value and the error is less than 1%. Note that the fifth effect, which is multiple state, is not used for verification since the model as it presently exists will not handle a multiple stage effect.

D. FUTURE WORK ON THERMAL EVAPORATION

The model will be expanded to handle multiple stage effects.

TABLE 8

Input Parameters and Comparison of Predicted Versus Experimental Values for X_e

Effect	X_i	J_i lb/hr	h_{V_e} Btu/lb	T_{V_e} °F	h_{J_e} Btu/lb	T_{J_e} °F	h_{J_i} Btu/lb	T_{J_i} °F	C_e lb/hr
1	13.2	45,172	1,142	191	146	192	140	206	10,566
2	16.4	36,215	1,135	173	126	174	145	192	8,956
3	21.5	27,783	1,128	155	104	157	125	174	8,432
4	29.9	19,799	1,112	118	65	122	104	157	7,984

Effect	h_{C_i} Btu/lb	h_{C_e} Btu/lb	T_{C_e} °F	S_i lb/hr	h_{S_i} Btu/lb	T_{S_i} °F	Q_p Btu/lb	Q_L	X_e Pred.	X_e Exp.	Error
1	0	180	212	10,566	1,150	212	944,357	1,079,668	16.4	16.4	0
2	0	158	191	8,956	1,143	191	936,037	87,966	21.4	21.5	0.4
3	0	136	173	8,432	1,133	173	719,709	83,671	30.1	29.9	-0.6
4	0	120	155	7,984	1,127	155	1,110,764	80,031	47.2	48.2	2

5.4.3 Cogeneration - Brayton and Diesel

In this section, a thermodynamic model is developed for a combustion engine/generator/waste-heat boiler combination. The model gives relations for work and steam output in terms of fuel input and system performance characteristics. An energy flow diagram of the system is shown in Fig. 25. Fuel energy, F, enters the engine/generator unit and is converted to electricity and heat. Most of the electrical output, W_e, becomes plant power, and, a small portion, W_a, is consumed internally in trubine/generator auxiliaries. Most of the heat becomes engine exhaust energy, E, and the rest, L, is lost to the atmosphere. Exhaust energy serves as heat input to the waste heat boiler. Part of it goes to steam energy, S, and the rest goes up the stack.

Work output, W, and steam production, S, are of main interest. The work output, W, is the work from the engine/generator, W_e, minus the work consumed by the auxiliaries, W_a.

$$\begin{aligned} W &= \text{work output} \\ &= W_e - W_a \end{aligned} \tag{1}$$

W_e = work output from engine/generator
W_a = work consumed by auxiliaries

W_a is proportional to W_e.

$$W_a = a\,W_e \tag{2}$$

a = proportionality factor for auxiliary electrical consumption

So that,

$$W = (1-a)\,W_e \tag{3}$$

W_e is proportional to the fuel input, F.

W_e = electrical output of engine/generator
η_{eg} = efficiency of engine/generator unit
F = fuel energy input (4)

Substitution of Eq. (4) into Eq. (1) yields the result for W.

$$W = (1-a)\eta_{eg}F \tag{5}$$

The steam output, S, is the product of the boiler efficiency, η_b and the energy input into the waste heat boiler, E.

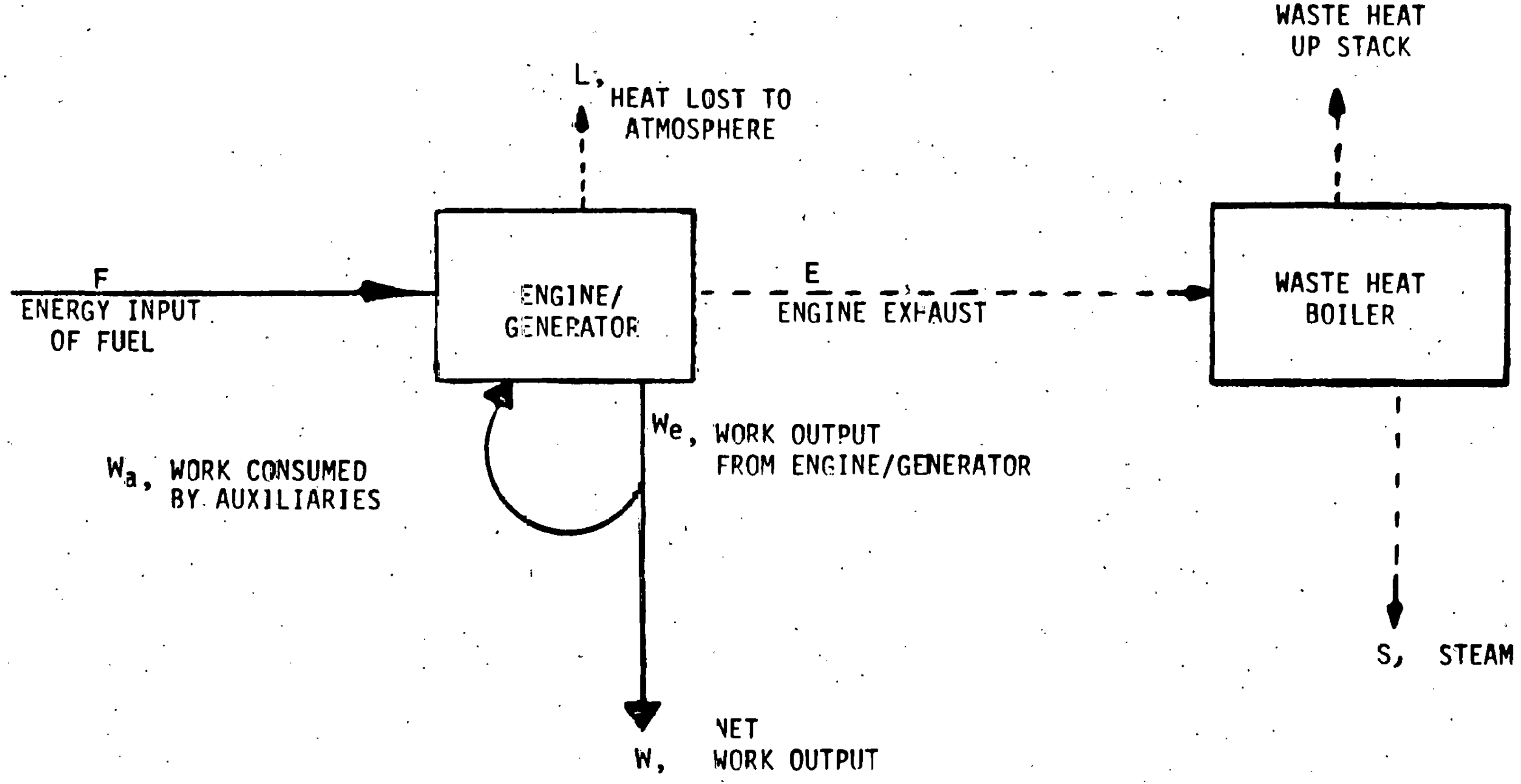


FIGURE 25, ENERGY FLOW DIAGRAM FOR COMBUSTION ENGINE/WASTE-HEAT BOILER COMBINATION

$$S = \text{steam production} = \eta_b E \qquad (6)$$

η_b = boiler efficiency
E = energy in engine exhaust

The term E is given by an energy balance about the engine/generator.

$$E = F - W - L \qquad (7)$$

L = heat lost to atmosphere from engine generator

L is proportional to the fuel energy input, F.

$$L = \ell F \qquad (8)$$

So that,

$$E = (1-\ell)F-W \qquad (9)$$

Substitution of Eq. (5) and (9) into Eq. (6) gives the result for steam production.

$$S = \eta_b \left[1-\ell-(1-a)\,\eta_{eg}\right] F \qquad (10)$$

Table 9 presents typical values of input variables for a gas turbine installation.

Parameter	Variable	Typical Values
Work consumed by auxiliaries divided by work output of engine generator	a	.006-.034
Efficiency of engine/generator	η_{eg}	0.19-0.31
Heat loss of engine/generator	ℓ	0.01-0.03
Efficiency of waste-heat boiler	η_b	0.65-0.75

TABLE 9: TYPICAL VALUES FOR EQUIPMENT PERFORMANCE PARAMETERS FOR COMBUSTION ENGINE/GENERATOR/WASTE-HEAT BOILER

APPENDIX I - Applicable (SCAQMD)[a] Rules and Regulations

(1) SCAQMD Rule 476 - Steam Generating Equipment

(a) A person shall not discharge into the atmosphere from any equipment having a maximum heat input rate of more than 12.5 million kilogram calories (50 million BTU) per hours used to produce steam, for which a permit to build, erect, install or expand is required after May 7, 1976, air contaminants that exceed the following:

(1) Oxides of nitrogen, expressed as nitrogen dioxide (NO), calculated at 3 percent oxygen on a dry basis averaged over a minimum of 15 minutes, as shown in the following table:

FUEL	GAS	LIQUID OR SOLID
Concentration	125 ppm NO	225 ppm NO

When more than one type of fuel is used, the allowable concentration shall be determined by proportioning the gross heat input and allowable concentration of each fuel.

(2) Combustion contaminants that exceed both of the following two limits:

(A) 5 kilograms (11 pounds) per hour.

(B) 23 milligrams per cubic meter (o.01 gr/SCF) calculated at 3 percent oxygen on a dry basis averaged over a minimum of 15 consecutive minutes.

(b) Nothing in this rule shall be construed as preventing the maintenance or preventing the alteration or modification of existing steam generating equipment which will not increase the mass of air contaminant emissions.

(2) SCAQMD Rule 407 - Liquid and Gaseous Air Contaimiants

Carbon monoxide measured on a dry basis, averaged over a minimum of 15 consecutive minutes.

(3) No specific rule has been promulgated concerning hydrocarbons from boilers or gas turbines in this size range.

(4) SCAQMD Rule 404 (c) - Particulate Matter-Concentration

Steam generators and gas turbines are exempted.

SCAQMD Rule 405 - Solid Particulate Matter, Weight

(a) A person shall not disscharge into the atmosphere from any source, solid particulate matter including lead and lead compounds, in excess of the rate shown in Table 405 (A).

Where the process weight per hour is between figures listed in the table, the exact weight of permitted discharge shall be determined by linear interpolation.

(b) A person shall not discharge into the atmosphere in any one hour from any source, solid particulate matter including lead and lead compounds, in excess of 0.23 kilogram (0.5 pound) per 907 kilograms (2000 pounds) of process weight.

For the purposes of this subsection only, process air shall be considered to be a material introduced into the process when calculating process weight.

(c) For the purposes of this rule, emissions shall be averaged over one complete cycle of operation or one hour, whichever is the lesser time period.

(5) SCAQMD Rule 409 - Combustion Contaminants

Combustion contaminants measured as grams per cubic meter (grains per cubic meter (grains per cubic foot) of gas calculated to 12 percent of carbon dioxide (CO) at standard conditions averaged over a minimum of 15 consecutive minutes.

(6) SCAQMD Rule 475 - Electric Power Generating Equipment

(u) Alternative Energy Projects

(1) Exemptions: The provisions of this Rule, exclusive of Subsection (u) (2) of this Part, are not applicable to a cogeneration unit(s) or a unit(s) in which refuse-derived fuel or biomass-derived fuel is burned to satisfy at least 50 percent of the total heat demand of that unit (s). For the purposes of this Rule, cogeneration unit(s) means any electric power generating unit(s) which concurrently recovers for sale by the electric power generating system owner or operator a substantial fraction, to be determined by the Executive Officer but in no event less than 25 percent, of the input energy as other forms of energy for utilization for industrial or commercial heating or cooling purposes. For the purpose of this Rule, cogeneration units do not include combined cycle generating units.

(2) Modified Units: All existing units which are not exempted from the provisions of this Rule pursuant to Subsection (u) (1) of this Part, shall, for the purposes of this Rule, be considered new units and shall be subject to the provisions of Rule 213. (Standards for Permits to Construct: Air Quality Impact).

(7) Best Available Control Technology (BACT) means the more stringent of:

(1) The most effective emission control techniue which has been achieved in practice, for such permit unit category or class of source, or

(2) The control technique which will result in the most stringent emissions limitation contained in any state implementation plan approveed by the Environmental Protection Agency for such permit unit category or class or source unless the owner or operator of the proposed source demonstrates to the satisfaction of the Executive Officer that such control techniques are not available (i.e., that such emissions limitations are not presently

achievable). No control technique, the application of which would result in emissions from a new or modified source in excess of the amount allowable under applicable new source performance standards specified in Regulation IX of these Rule and Regulations may be considered Best Available Control Technology, or

(3) Any other emissions control technique found, after public hearing, by SCAQMD or the Air Resources Board to be technologically feasible and cost/effective for such class or category of sources or for a specific source.

(8) BACT required. BACT for gas turbines is water or steam injection.

(9) New Source Performance Standards (NSPS). NSPS have not been promulgated for this size of equipment.

(10) Sulfur content of natural gas must be 80 ppm or less (calculated as hydrogen sulfide) (SCAQMD Rule 431.1).

(11) New Source Review Rule (NSR). SCAQMD Regulation XIII concerns procedures to be followed and limitations to be met by new source of air contaminants.

SCAQMD Rule 1303 - Applicability and Analysis

(a) Applicability

The provisions of this regulation shall apply to new stationary sources or modifications to existing stationary sources and relocation to non-contiguous property of existing stationary sources as provided in subsection (c) which result in a net emission increase from such stationary source of any air contaminant greater than 68 kilograms (150 pounds) per day except carbon monoxide for which the value is an increase of 340 kilograms (750 pounds) per day.

(b) Analysis

The Executive Officer shall deny the permits to construct for permit units subject to this regulation as provided by Rule 1303 (a) unless:

(1) The new source or modification complies with all applicable rules and regulations of the District; and

(2) The applicant certifies in writing prior to the issuance of such permit that all stationary sources owned or operated by such person (or by any entity controlling, controlled by, or under common control with such person) in the State of California are in compliance with all applicable emission limitations and standards under the Clean Air Act (42 USC 7401 et, seq) and all applicable emission limitations and standards which are part of the state implementation plan approved by the Environmental Protection Agency or on a compliance schedule approved by the appropriate federal, state or district officials. The requirements of this subsection shall apply to stationary sources with allowable emissions of any air contaminant of 25 tons per year or more; and

(3) The new source or modification will be constructed using BACT for each affected air contaminant. In carrying out this provision, the Executive Officer shall annually publish a guideline of BACT for commonly processed permit unit categories or classes of sources. BACT dfor other permit unit categories or classes of sources shall be determined on a case-by-case basis; and

(4) The net increase in emissions for each affected air contaminant has been offset pursuant to Rule 1307; and

(5) The applicant has substantiated with modeling or other analyses approved by the Executive Officer that the new source or modification will not cause a violation or make measurably worse an existing violation of any national ambient air quality standard at the point of maximum ground level impact. However, modeling shall not be required if all offset sources are within a distance of 8 kilometers (5 miles) from the affected permit units; and

(6) The Executive Officer determines that the new source or modification will not result in emissions which interfere with the schedule of reasonable further progress set forth in the state implementation plan for the South Coast Air Quality Management District, approved by the Environmental Protection Agency.

(c) The provisions of this regulation shall apply to existing stationary sources relocated to non-contiguous properties, provided:

(1) The relocation distance is greater than 8 kilometers (5 miles) and the emissions of any air contaminant, at the new location, are greater than 68 kilograms (150 pounds) per day except carbon monoxide for which the value is 340 kilograms (750 pounds) per day; or

(2) The relocation distance is less than 8 kilometers (five miles) and there is a net emission increase of any air contaminant greater than 68 kilograms (150 pounds) per day except carbon monoxide for which the value is an increase of 340 kilograms (750 pounds) per day.

SCAQMD Rule 1304 - Exemptions from Regulation XIII

Upon approval by the Executive Officer, and provided BACT is employed on the subject permit units, an exemption from this regulation, for one or more air contaminants as appropriate, shall be allowed for the permit unit or source which:

(e) Resource Conservation and Energy Projects

Is a cogeneration project, a project using refuse-derived or biomass-derived fuels for useful energy generation, a resource recovery project usuign municipal wastes, or other energy related project but excluding such other energy-related projects at power plants or refineries, provided:

(1) the applicant establishes by modeling that the affected source will not cause a new violation or make measurably worse an existing violation of any national ambient air quality standard at the point of maximum ground level impact; and

(2) the applicant demonstrates that best efforts have been made to obtain the required emission offsets, and that the applicant certifies that required offsets will be sought until construction of the affected source begins, and that all required offsets available shall be used; and

(3) The Executive Officer determines that the project will not interfere with the schedule of reasonable further progress set forth in the state implementation plan for the South Coast Air Quality Management District, approved by the Environmental Protection Agency;

(12) <u>SCAQMD Rule 1302</u>

(g) Cogeneration Project means a project which

(1) makes use of exhaust steam, waste steam, waste steam heat, or resultant energy from an industrial, commercial, or manufacturing plant or process for the generation of electricity, or

(2) makes use of exhaust steam, waste steam, or heat from a thermal power pant, in an industrial, commercial, or manufacturing plant or process.

For the purposes of this definition the "industrial, commercial or manufacturing plant or process" shall not be a thermal power plant or portion thereof. A cogeneration project shall not consist of steam or heat developed solely for electrical power generation. To qualify as a cogeneration project, the processes listed in (1) and (2) above must concurrently recover for useful purposes, at the first stage of heat transfer, not less than 25 percent of the energy.

(13) Limits (Net Increase of any specific pollutant, e.g., NOX)

1. 15 lbs/hr, 150 lbs/day

   A. BACT required

      BACT is water injection

2. 15 to 25 lbs/hr, 150 to 250 lbs/day

   A. BACT required

   B. Exemption per SCAQMD Rule 1304 (see note 11)

3. 25 lbs/hr, 150 to 250 lbs/day

   A. BACT required

   B. Emission offsets from offsite source

   C. Air modeling which shows no worsening of any national ambient air quality standard

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