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PROCESS ENERGY INVENTORY AT RADFORD ARMY AMMUNITION PLANT

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WEAPON SYSTEMS LABORATORY
DOVER, NEW JERSEY

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This project was accomplished as part of the U.S. Army's Manufacturing Methods and Technology Program. The primary objective of this program is to develop, on a timely basis, manufacturing processes, techniques, and equipment for use in production of Army materiel.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Process operations at Radford Army Ammunition Plant were audited to measure energy consumption, identify areas of inefficiency, and identify changes which would reduce process energy requirements. The audited operations included nitrocellulose manufacture, propellant drying and solvent recovery.

The study identified process changes available for immediate implementation which will result in annual energy savings of 1,435,000 MBTU under

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20. ABSTRACT (cont)

mobilization production rates. Further studies were proposed with an additional annual potential savings of 1,557,000 MBTU. This totals to an equivalent saving of approximately 460,000 barrels of oil or 107,000 tons of coal per year.

Recommendations include automatic control of boiling tub steam, insulation of boiling tubs, heat recovery from wastewater, demand cycle control of the activated carbon solvent recovery operation, elimination of preheating of solvent laden air, and electric power generation using waste heat from hot condensate and exhaust gases via Organic Rankine Cycle Engines.

SUMMARY

Several operating areas at Radford Army Ammunition Plant (RAAP) were monitored to determine which were the most energy intensive and to identify processing changes which could effect the most energy conservation. These operations were: (a) cotton and woodpulp preparation, (b) nitrocellulose (NC) purification, including boiling tubs, Jordan Beaters, poaching and blending operations, (c) open tank air dry, (d) forced air dry, (FAD) (e) rolled powder, (f) activated carbon solvent recovery, and (f) ether manufacture and alcohol rectification.

This study has identified areas for processing alterations resulting in an energy savings of 1,435,003 M Btu/yr [based on mobilization rate (MOB)] with immediate processing changes. Additionally, further studies were proposed with potential energy savings of 1,501,091 M Btu/yr steam and 56,271 M Btu/yr equivalent of electrical power generation. This is equivalent to approximately 460,000 barrels of oil per year, or 107,000 tons of coal per year. Some of these projects have already been implemented and others are in various stages of evaluation and approval (see summary of energy conservation table below).

Electrical generation with Organic Rankine Cycle Engines (ORCEs) using waste heat in the form of hot condensate and exhaust gases, and the use of topping turbines in certain operations were recommended.

An evaluation of the use of capacitors near the load on electric motors to reduce reactive components and increase power factors was presented and resulting energy savings estimated.

The use of insulation was emphasized in certain operations and a project to insulate the boiling tubs was recommended.

The recovery of heat from hot wastewater was emphasized, where this recovery could be utilized in the process, and projects were submitted for their study.

Summary of Energy Conservation

Process	kg x 10^6 per yr	lb x 10^6 per yr	KWH x 10^3 per yr	Btu x 10^6 per yr
1. Boiling Tubs (Automatic Control)[1]	292.59	643.71	---	756,764
2. Activated Carbon Solvent Recovery				
(a) LEL Meter Control[1]	233.48	514.73	---	605,116
(b) Elimination of Preheated Solvent-Laden Air [2]				73,123
3. Poacher Tubs				
(a) Automatic Controls [3]	42.08	92.26		109,050
(b) Waste Heat Recovery [3]	517.30	1140.43	---	1,340,690
4. Electrical Motors (Power Factor Correction)[3]	---	---	16,477	56,271
5. Topping Turbine[3]	---	---	33,128	113,130

1/ Implemented

2/ Elimination of preheating of solvent-laden air has improved recovery efficiency amounting to an increase of 1,491,390 lbs ether/year and 295,650 lbs alcohol/year.

3/ Under evaluation

CONTENTS

CONTENTS

TABLES

FIGURES

INTRODUCTION

The purpose of Production Engineering (PE) Project PE-432 was to assess processing operations at RAAP as part of the Modernized Munitions Production Base Program to determine areas where energy savings could be effected. The first phase of work included establishment of methodology for evaluation and performance of the energy inventory with data accumulation and analysis. This work defined those processes and system changes which could be made without further project study. The second phase was to produce preliminary design criteria for process changes, perform economic analysis of changes, and define follow-on projects.

The benefits derived from this project included an assessment of energy utilization at RAAP, cost estimates and work plans for follow-on projects dealing with further process evaluation to establish energy conservation methods, flow diagrams, heat balances, energy usage information, work scopes, and cost estimates for all necessary modification work. The overall effort assessed methods to minimize heat loss, maximize heat recovery and to use available energy more efficiently.

The theoretical energy requirements of selected high energy utilization processes were determined. In each process, where feasible, these theoretical values were obtained and compared to actual measured values and theoretical to actual ratios determined. This gave an initial concept of the potential energy savings in these processes and the degree of effort that should be exercised to effect these savings.

ENERGY CONSUMPTION AT RAAP -- BACKGROUND

The energy usage at RAAP is dependent upon production rates. The processing complex has extensive energy requirements that encompass large areas which are subdivided into many small energy users. This, therefore, makes a total energy balance of each processing area more difficult; however, current and future energy costs and potential savings justify the effort to make an accurate assessment.

This project assesses energy usage in terms of production, i.e., the amount of energy required to produce a unit quantity of product. This allows one to make an energy consumption evaluation at various production rates.

The major steam and electrical energy users at RAAP were selected to be monitored in this project.

Electrical

Electrical usages in the major operations were related to production and a "KWH-to-product" ratio established. Electrical energy usage may be reduced by one, or a combination of three methods:

1. Increase motor efficiency by more efficient motor loading.

2. Replace inefficient motors with energy efficient motors.

3. Install external capacitors near the load to reduce the total reactive load, thus reduce line current and increase transformer Kva capacity.

Installation of capacitors appears to be the most appropriate and immediate energy conservation method. Capacitors are used at certain distribution equipment; however, to be more effective, capacitors should be installed near the load.

An overall plan to replace present electrical motors with energy efficient motors, as they are needed, is part of the plant energy conservation program.

Steam

The steam metering capability at RAAP was limited to only the major distribution lines leaving the Power House; consequently, the amount of steam used for each processing area had not been measured. Steam flow to small steam users can be determined with sufficient accuracy by measuring condensate or by heat balance calculations. However, large users must be metered by additional steam measuring equipment. Figure 1 shows a schematic flow diagram of all steam users at RAAP.

Preliminary studies showed that major project efforts should be directed to operations within the nitrocellulose (NC) manufacturing area, because a large percentage of all steam used in manufacturing operations was consumed by the NC Area and supporting operations.

Theoretical energy requirements of selected high energy consuming processes in various areas were calculated. This was followed by the purchase, installation, and utilization of steam and electrical monitoring instrumentation to measure actual usage. These data were used to establish actual to theoretical ratios and to quantify the energy consumed per unit of product manufactured.

ENERGY GENERATION

The generation of steam and electricity at RAAP is by coal-fired boilers. These boilers constitute the largest users of fuel at RAAP; therefore, improving the efficiency of the boilers at the Power House and reducing the amount of steam required in the various processes have the greatest potential for energy savings. Combustion efficiency at the Power House was covered in a separate report.[1]

The steam distribution system for RAAP is shown in figure 1.

The effectiveness of any steam conservation program is dependent upon the following:

1. Can some or all of the heat load be provided by a waste heat recovery source?

2. Is the lowest necessary steam pressure being used?

3. Can topping turbines be used to reduce pressure and produce electricity?

4. Is the minimum flow rate being used?

5. Is proper control being provided on the steam supply?

6. Is any heat being lost unnecessarily?

7. Is electrical power being used efficiently?

Attempts to answer these questions were made in each process throughout the energy survey.

ENERGY AUDITS

Du Pont Company

Two energy surveys have been completed at RAAP, and one is presently in progress. The first was performed by E. I. du Pont de Nemours and Company, Wilmington, Delaware, in 1975. The Du Pont survey outlined existing energy saving for on-going programs by the Operating Contractor, in addition to other energy saving possibilities that were not in progress. The report also emphasized the overall energy savings potential at RAAP. The largest single item for potential energy savings reported was combustion efficiency (appendix A) of the boilers at the two power houses, with the quality of coal having the greatest influence. Other potential energy savings outlined were:

1. Increase heat recovery from boiler blowdown.

2. Use air compressor cooling water for boiler feed make-up.

3. Reduce steam leaks.

4. Reduce length of steam lines in service.

5. Improve turbogenerator condenser performance.

6. Reduce compressed air leaks.

The report emphasized that a primary requisite in accomplishing these savings was a continuing energy conservation program. In addition, energy measurements to show where energy was being expended and in what quantities, and making maximum use of energy now lost, are basic to accomplishing these energy saving objectives.

TRW Corporation

In 1977, TRW, Defense and Space Systems Group, Redondo Beach, California, performed an energy survey at RAAP. The primary purpose of this survey was to determine the most appropriate application(s) of heat pipe technology and other heat transfer methods for achieving process energy savings. The boiling and poaching steps of NC purification were identified as the most appropriate areas for heat recovery application. The boiling tub house was selected for energy recovery because the poaching operation may be replaced by the CONICELL Process. In addition, the boiling tub process had a good return on investments

(ROI) which was the economic approach emphasized to analyze candidate energy recovery systems.

Other processes identified by TRW as having potential energy recovery, in descending order of priority, are:

Process	Recovery Concepts
Boiling Tub Houses	Preheat incoming water
Waste Propellant Incinerator	Preheat incoming air
Ammonia Oxidation Plant	Preheat ammonia
Sulfuric Acid Concentrator	Preheat air
Continuous Automated Single-Base Line	Heat inert gas
Nitric Acid Concentrator	Preheat spent acid and nitric acid feed
Activated Carbon Recovery	Use inert carrier gas to transport vapors to condenser instead of steam

NITROCELLULOSE MANUFACTURING

NC is manufactured by treating cellulose with a mixture of nitric and sulfuric acids, and then it is purified in a series of boiling operations to remove the residual acids, (fig 2).

Cellulose for nitration is obtained from woodpulp or cotton linters. This cellulose must be prepared before it is treated with acid. The pulp is shredded and the cotton is broken up from the bale by picking machines. The energy used in this process is supplied from several electric motors of varying horsepower (440 V). The linters are subjected to a drying treatment, whereby, as much moisture as practical is removed by passing these fibers through an oven heated by steam coils supplied by 40-pound steam.

The cellulose is treated with mixed acid producing NC. The majority of the acid is removed and the NC transferred to a purification area. Here NC is extensively boiled, washed, and neutralized to remove any remaining acid. This process takes place initially in boiling tubs heated by 40-pound steam. From boiling tubs, the NC is pumped to storage tanks in the Jordan Beater Houses. These pumps are energized by 40 hp, 440 volt electric motors. In the beater houses, the NC is agitated and transferred to the Jordan beaters by pumps energized by 15 hp and 25 hp motors (440 V). The beater action finely cuts the NC which requires substantial quantities of 2300 V power supplied to seven, 200 hp Jordan beater motors. The NC slurry is heated by 40-pound steam and finally transferred to centrifugal wringers by pumps energized by 25 hp motors (440 V).

The entire NC purification process, including its associated operations, consumes a highly significant amount of the total energy used in the manufacturing processes at RAAP. For this reason, the NC manufacturing and purification areas offer high potential for energy conservation and, therefore, were given special emphasis for energy measurements in this project. Appendix B shows typical equipment used in these process energy measurements.

PROCESS ENERGY ASSESSMENT

Cotton Dry House

Bales of cotton linters and rolls of sheets of woodpulp are broken into fibrous particles, dried, and airveyed to the Continuous Improved Nitration Building (CIN).

Woodpulp

Woodpulp is fed into the dryer in the form of thin sheets. Two 75 hp motors drive two cutters that shred the pulp sheets prior to being airveyed to the CIN Building by a 35-inch blower driven by a 30 hp motor (fig 3). Table 1 shows that an average of 0.0367 KWH of electrical power is required to process one kg of woodpulp in this operation.

These motors do not contain external capacitors and, therefore, likely have relatively large reactive components which render the motors inefficient. To improve performance and conserve energy, external capacitors are recommended at the motor load to supply the magnetizing current for the motor and, therefore, reduce the reactive load and increase power factors, figure 4 and appendix C.

Additionally, it is recommended that all energy inefficient motors be replaced with high efficiency (HE) motors. The time frame to implement this recommended change will depend on the cost and availability of energy.

Figure 5 shows a comparison of the total cumulative operating cost of a standard and a high efficiency motor in a typical application during a continuous load, such as a pump. Although the HE motor has a premium price, its lower operating cost will amortize the extra cost and result in a cost savings.

The drying of pulp before nitration was discontinued. This saved an estimated 413,424 pounds of steam/month and 5140 KWH/month based on 1980-81 production of 1.8×10^6 pounds/month of pulp. This was equivalent to 0.23 pounds of steam/pound of pulp.

Cotton Linters

Steam

Cotton linter bales weighing 175 to 190 pounds each are shipped to the warehouse in railroad cars. The bales are fed to a bale breaker powered by a 5 hp motor and then to a picker. The picker is powered by a 10 hp motor. The cotton is transferred to a dryer apron by a spiked riser, powered by a 1.5 hp motor. The apron is powered by a 1.0 hp motor.

The cotton on the dryer apron is dried by five 800 rpm blowers which circulate air over steam coils. The coils are maintained at a temperature of 104°C to 110°C (220°F to 230°F) by 40 psig steam. Following drying, the cotton linters are transferred to a cross conveyor powered by a 1.5 hp motor. The cotton is then transferred to a blower hopper, where it is blown through a 15-inch diameter duct to the CIN Building (fig 6).

Experiments are presently beirg conducted to determine if the drying of linters before nitration can be discontinued as was pulp drying. An estimated savings of 118,589 kg/month (261,440 lbs/month) and a power savings of 2926 KWH/month could be realized based on the 1980-81 production rate of 0.5×10^6 pounds/month of linters. This is equivalent to 0.52 pounds of steam/pound of lint.

Electrical

As seen in table 1, 0.0864 KWH of electrical power was required to process each kg of cotton in this operation. These motors do not contain external capacitors and, therefore, are not optimized for energy efficiency. It was recommended that capacitors be installed on all motors (fig 7 and appendix C).

Boiling Tub House

NC from the CIN Building is fed, in the form of a water-NC slurry, to boiling tubs where the first phase of the purification process is performed. This process involves filling the tub with 13,608 kg (30,000 lbs) of nitropulp and 71,667 kg (158,000 lbs) of water, or 10,433 kg (23,000 lbs) of nitrocotton and 72,574 kg (160,000 lbs) of water. Forty pound steam is then used to attain, and to maintain, a minimum temperature of 96°C (205°F). A percolation action is normally required to maintain temperature equilibrium throughout the tub. The slurry is allowed to remain "on-boil" (designated "acid boil") for a time period which depends upon the type of NC being processed (table 2). Following this boil and the normal wash, the NC slurry is again brought up to 96°C (205°F) where it is allowed to remain for a period of five hours, designated the "first neutral boil". The water used for boiling is drained and the NC is given a second fresh water rinse as before, after which the slurry is brought up to a "second neutral boil" and remains for a period of five additional hours. Following this "boiling" period, the water is drained and the NC is again washed as before and the boiling tub house process is complete.[2]

A typical steam flow profile for a complete boiling tub cycle is shown in figure 8.

Steam

Measurement of Fourteen Tubs

To assess the 40-pound steam usage in this purification process, a steam meter was located as shown in figure 9. This location allowed the steam usage measurement of 14 boiling tubs, either individually or collectively, depending upon how many tubs were in operation at any given time. The quantity of NC processed through these 14 tubs was obtained on a monthly basis and related to steam usage, giving an actual steam usage to NC ratio. Theoretical values for both nitropulp and nitrocotton were calculated, (appendix D), and compared to actual values giving an actual to theoretical ratio. Figure 10 shows the actual steam to NC ratio for a period of 10 months to be 9.26 kg steam per kg of NC, with a high of 12.61 kg steam per kg NC recorded in a winter month. The overall actual to theoretical ratio is 3.398. The monthly actual to theoretical ratios for the same period are also shown in table 3. Mean temperatures are also plotted in figure 10 which show the influence of outside temperature on steam required to process NC through a boiling tub.

For the 22-month period shown in table 3, a total of 52,305,318 kg of steam in the boiling tub operation was required to process 5,646,154 kg of NC. At the rate of 9.26 kg steam/kg NC, the MOB production of 5.44×10^6 kg/month of NC would require 604.84×10^6 kg/year of steam consumption for the boiling tub operation. The steam capacity at Power House No. 1 is rated at $2{,}543 \times 10^6$ kg/year, therefore, the boiling tub processing represents 23.78% of the total steam capacity of the No. 1 Power House.

Single Tub Evaluation

During the evaluation of steam usage on the 14 boiling tubs it was observed that the amount of steam used for the boiling tub house operations varied with different building operators. In the "on-boil" cycle, it was generally observed that excess steam was used to insure that the 96°C (205°F) "on-boil" temperature was maintained. Some operators used considerably more steam than others. This was due to (1) the inability of operators to give sufficient attention to tubs "on-boil" because of other tasks that must be performed, and (2) the inability of operators to control steam valve openings precisely so the tub temperature could be maintained with minimum steam flow. The amount of steam required to process various types of NC is shown in table 4.

should be operated entirely with microprocessors if the 1982 operations are not replaced with the "CONICELL" purification process. This would make the operations more efficient, eliminate operator to operation process variations, and errors.

Electrical

After processing NC through the boiling tub cycles, the NC slurry is flushed out of the tubs with water and is pumped by four 1,000 gpm pumps to beater houses for additional processing. These slurry pumps are powered by 40 hp (440 volts) induction motors.

Table 6 shows that an average of 0.0127 KWH of electrical power is required to transfer one kg of NC from a boiling tub house to a beater house. The location of the electrical measuring meter in the boiling tub house is shown in figure 12.

The loads on the pump motors and the consequent motor power factors are largely determined by the effectiveness of operators to flush NC from tubs; low loads result in low power factors. Since the degree of reactive components of motors significantly affect its energy consumption in doing work, it is important that the motors operate as near to full load as possible. To accomplish this, a more effective means of flushing NC from tubs is necessary. Some recommendations are:

1. Provide larger discharge openings for tubs.
2. Agitate slurry while discharging.

Reactive current is necessary to build up fluxes for magnetic fields of inductive motors. Since this energy does no useful work in pumping slurry, electrical energy can be conserved by reducing this reactive component. This can be done by installing external capacitors on these motors which serve to generate the magnetizing power required by these motors. Figure 7 shows a typical power factor diagram and appendix C shows the energy that can be expected to be conserved by installing capacitors on or near motors.

Beater House

The purpose of beater houses is to reduce NC to a fineness and freeness consistent with optimum propellant production. This is accomplished by cutting NC with Jordan beaters.

As shown in figure 13, beater houses contain 18 feet by 12 feet high wooden tubs. Each of two receiving tubs is agitated by two pairs of propellers, directly driven on horizontal shafts by 440 V (25 hp) induction motors. One of two similar pumps and motors feed the secondary Jordans, making a total of five 15 hp motors.

Cutting equipment in beater houses consist of six Jordan beaters, each driven by a 200 hp 2300 volt, 300 rpm, synchronous motor. Two Jordans are designated primaries and four as secondaries. Electric starters are provided allowing correct amounts of AC and DC current inputs.

Table 7 shows the electrical energy used in a beater house to process NC through the operation. An average of 0.033 KWH of 440 volt power per kg of NC is necessary to agitate and pump NC slurry. Likewise, an average of 0.2308 KWH of 2300 volt power per kg NC was necessary to process this NC through the Jordan beaters.

Since these induction motors do not normally operate at full load, their power factors are obviously low; therefore, it is recommended that external capacitors be installed on all 440 volt induction motors. This feature will significantly reduce reactive loads, thus improving motor efficiency and conserving electrical energy.

The use of electrical power by Jordan beater motors is primarily dependent upon operator alertness and judgment. Since these motors are synchronous and DC current supply to the field windings is intrirsic within the motor, the power factor is normally better than induction motors; however, the addition of capacitors needs to be evaluated.

Poacher Tub House

Steam

Poacher house operations follow the beater house operations, and are a series of NC boils and washes. The first boil is a soda ash boil, which neutralizes any acid that may have been released in the beater operation and is still in the NC. Subsequent boils and washes are designed to wash out excess soda ash, thus bringing the NC to a neutral state.

As shown in figure 14, steam is supplied to each poacher tub by two 3-inch lines which extend downward inside the tub approximately 10 feet. Excess water is removed by decanting. During the steam measuring operation 7 wooden tubs and 11 stainless steel tubs were used in the poaching operation. Two additional wooden tubs were used for tail water settling, and two stainless steel tubs were used for storage.

Steam is used to bring the NC-water slurry to the "on-boil" temperature of 96°C (205°F), four times per treatment, and to maintain this temperature for a total of eight hours. Table 8 shows the total poaching treatment given. Steam requirements are governed by the volume and temperature of the water, NC, and tank mass as well as temperature maintained during the treatment. The time-temperature profile for a typical poacher cycle is shown in figure 15.

Appendix F shows the theoretical steam required for the poaching process through both stainless steel and wooden tubs. As shown, 2.158 kg steam per kg NC is required in a stainless steel tub, and 2.463 kg steam/kg NC for processing through a wooden tub. The actual steam measurements taken for a three-month operating period is given in table 9. The steam used for poaching could not be separated into steam used by wooden tubs or stainless steel tubs, because both types of tubs were operating on the same steam header. The wooden tubs are being replaced by stainless steel tubs as they wear out, so there is no order to their arrangement in the poacher building. These measurements averaged 4.7 kg steam/kg of NC processed, which gave an actual to theoretical ratio average of 1.88.

Poacher houses, because of the large volume of approximately 96°C (205°F) water discharged, offer high potential for heat recovery and short payback. A heat pipe heat exchanger (HPHX), or shell and tube heat exchanger, could extract heat now lost from these wastewaters and be used to heat fresh make-up water for the poacher tubs. As appendix G shows, the total energy saved using a HPHX recovery system at MOB would be 13.379×10^{10} Btu/year.[3] However, this recovery system is held in abeyance in favor of a CONICELL process which, if successful, will render the poaching process obsolete.[4]

Estimated savings using automatic temperature controls on poacher tubs are shown in appendix H. These savings are based on results obtained during boiling tub measurements and normalized for the lesser water and NC masses in poacher tubs. The savings translate to $109{,}050 \times 10^6$ Btu/yr.

Electrical

Paddle agitators in each of 22 poacher tubs are driven from a line shaft, running the length of the poacher house, powered by two 100 hp, 2300 volt, electric motors. Two 30 hp, 440 volt, motors power two 600 gpm pumps to pump NC fines from the tail water tubs. Two 14 hp, 440 volt, motors pump NC from the receiving tubs to the filters. The filters are powered by two 3 hp, 440 volt, motors through Reeves drives, and two 15 hp motors are used in pumping NC from storage tubs to the blender tubs. The arrangement of these motors and the position of the electrical monitoring meters are shown in figure 16.

Electrical energy measurements for the poaching operation were obtained at three separate locations for the 440 volt power, and data from the three were summarized to arrive at the total 440 volt power. Table 10 shows the energy values obtained and translated in terms of NC production. As shown, 0.072 KWH of 440 volt power is required to process one kg of NC through this operation.

To conserve electrical energy in the poacher house, it was recommended that: (a) all 440 volt electric motors be replaced by more energy efficient motors; (b) external capacitors be installed near the load on all motors to minimize the reactive component; and (c) to size motors in the future so they will operate at or near capacity, thus increasing motor efficiency, reducing power and conserving energy. These recommendations should be implemented if the CONICELL system does not replace the poaching operation.

Electrical measurements of energy consumed by the 100 hp, 2300 volt, synchronous motors were obtained from existing in-line amp meters. These data were used to compute electrical power (KWH). Table 10 shows that 0.088 KWH per kg of NC is required to drive the poacher tub agitators. Table 10 also shows that the overall electrical power required to process NC through the poacher is 0.160 KWH/kg NC.

Blender House

The blender house operation is designed to remove uncut particles and foreign material by screening, to remove any residual soda ash from NC by washing with a vacuum filter system, and to prepare NC blends within the specified limits for the manufacture of various types of propellants. The blending operation contains 28 tubs, each of which is equipped with an agitator powered by a 10 hp, 440 V motor and two shaker screens. Fourteen 25 hp, 440 volt, motors power pumps that circulate NC between tubs of a blending unit. The power required by these motors is given in table 10.

Single-Base Open Tank Air Dry

In an open tank air dry operation, 2359 kg (5200 lbs) of single-base propellant is loaded into a steel tank, where it is dried by blowing 5500 cfm of 63°C (145°F) air through the propellant bed. This air is heated by steam coils and is forced through the propellant beds by a blower powered by 7-1/2 hp electric motors (fig 17). Drying times vary depending upon the temperature and moisture content of the ambient air, and the type of single-base propellant being processed.

Steam

Appendix I shows that theoretically 0.363 kg of steam per kg of propellant is necessary to dry single-base propellants having 8-hour drying cycles. The actual steam required for this drying period varied from 1.4 to 5.29 kg of steam/kg of propellant depending on type of propellant being processed (table 11).

The time required to sufficiently dry a propellant batch is estimated based on previous drying times and ambient air temperature and humidity. Attempts were made to define a more precise drying time cutoff by measuring effluent air temperature and humidity. Previous drying studies have indicated a slight temperature rise of the effluent air near the end of drying. This method was not sufficiently successful to use as the end point of drying operations, since the change in temperature was not consistent, or discernible, for each cycle. More sensitive temperature measuring equipment would be required to establish this concept.

An alternate method is shown in figure 18. This approach would measure the air temperature and humidity. When these two parameters are below a predetermined value, then ambient air only would be used for the first part of the air dry cycle. Heated air is required near the end of the cycle to remove the moisture in the propellant to the specification level.

Project PE-548[5] proposes to remove solvents, water dry, and air dry single-base propellants in the same tank. This project may use the above approach in the air drying process when implemented.

Heat Recovery

The 5500 cfm effluent air from each open tank air dry is approximately 63°C (145°F). This heat is lost since the air is exhausted to the atmosphere. A proposal has been submitted to recovery this heat by using an air-to-air heat exchanger to preheat incoming air.[6]

Electrical

In each air dry tank, a 20 hp, 440 volt, electric motor drives a 5500 cfm blower continuously throughout the drying process. Table 12 shows that an average of 0.0239 KWH of electrical energy per kilogram of single-base propellant is required.

Since these motors are induction types, the installation of a capacitor near the load to reduce the reactive motor component has been recommended. Also, to purchase and install energy efficient motors, as replacements that are sized to operate at or near full load, has been recommended.

Forced Air Dry

In a FAD multibase (double- and triple-base) propellants are dried by forcing hot air around the propellant for a specified time. One FAD contains four bays, with each bay having a loading capacity of 5670 kg (12,500 lbs) as shown in figure 19. Because of condensation problems with solvent and nitroglycerine (NG), the loading is limited to 3920 kg (8,640 lbs) dry weight of propellant. Ambient air is heated to 60°C (140°F) by steam coils and forced through these bays at a rate of 5500 cfm for times ranging from 40 hours to 144 hours. The energies consumed are in the forms of steam to heat the air, and electrical power to drive the blowers.

Steam

Forty pound steam is directed through coils that heat incoming air to the drying bays. Table 13 shows that the steam required to dry propellant varies with the type of propellant being dried. The longer the drying time, the higher the kg of steam to kg of propellant ratio. The theoretical amount of steam required is 1.31 kg of steam per kg of propellant (appendix J). The quantity of steam for three FAD cycles that was required to bring the propellant bay temperature to 60°C (140°F), and maintain the 60°C (140°F) temperature, is given in table 14.

Steam measurements were recorded at FAD Building 4912-47. These measurements were initiated in June 1978, and continued at various periods until June 1979. For the one year monitoring, the average steam usage rate varied from 351 kg/hr to 707 kg/hr. The usage rate during the summer months average 601 kg/hr.

The steam usage was recorded during the off cycles and varied from 0 to 56 kg/hr. This indicates that the steam control valves were not always shut off between cycles. For steam conservation the valves should be shut off at the completion of each cycle except in winter to prevent freezing. Also, steam trap maintenance is important to maintain FAD steam usage at a minimum.

Electrical

Two 10 hp, 440 volt, induction motors are used to drive two 11,000 cfm blowers. Each 11,000 cfm blower supplies two bays in the FAD. A diverter in each system directs 5500 cfm of hot air to each bay. As shown in table 15, these motors consume an average of 0.069 KWH of power per kg of propellant throughout the 40 to 144 hour drying periods. When a proposed improved drying design is implemented, smaller motors can be used to supply the reduced air flow of 1500 cfm.[7]

Fourth Rolled Powder

In a rolled powder area, solventless propellant paste is rolled into sheets. The metal rolls that form these sheets are maintained at an elevated temperature by circulating 104°C (220°F) hot water from an insulated water storage tank. This tank is heated by steam and is the major steam user in a rolled powder area. In addition, steam is used to heat the circulating water, used to keep propellant transport buggies warm, and for space heating in cold weather.

Steam

As shown in figure 20, space heating in cold weather has a highly significant influence on steam usage in rolled powder areas. Steam usage measurements over a period of one year in one operating building show a range from 18.64 kg steam per kg propellant processed in summer months to 44.28 kg steam per kg propellant processed in winter months. The average for a full year is 31.56 (table 16). The steam usage in June was the highest recorded which was contrary to the trend. Reasons for this high usage could not be identified.

The distance for transporting steam from the Power House to the rolled powder areas at RAAP is approximately two miles, which contributes to energy inefficiency. At reduced production rates, distribution line losses associated with supplying steam to a remote rolled powder area, such as Fourth Rolled Powder, may be greater than steam actually used in the area. For the rolled powder area assessed in this report, steam pressure is reduced from 400 pounds to 40 pounds for the boiler and 5 pounds for space heating radiators. Recommendations have been made to install packaged boilers to eliminate steam transport and thus minimize energy losses.[8] Also, a recommendation has been made to install a topping turbine at a steam pressure reducing station to generate electricity.

Activated Carbon Solvent Recovery

The air exhaust system in the single-base green lines removes solvent vapors from the operating bays and passes them through activated carbon (AC) beds. The AC adsorbs the solvents (ethyl ether and alcohol) from the exhaust air. The solvents are then recovered for reuse by steam regeneration (fig 21). Steam is used to preheat the air/solvent vapors in a tempering unit. This unit consists of steam coils which preheat the vapors to 43°C (110°F). The amount of steam fed to the tempering unit is proportional to the vapor temperature leaving the unit. The vapors are then fed into the adsorbers and forced down through the AC beds. Ether and alcohol are adsorbed by the AC. Following an adsorption period, steam is introduced to vaporize the solvents and carry the ether and alcohol to the condensers. This process requires approximately 3.9 kg of steam per kg of solvent recovered. Only 0.5 kg of steam is used to vaporize the solvent while the remaining serves as vapor carrier.[9]

Regeneration Cycle

The steam regeneration cycle was normally conducted on a fixed time schedule. This schedule, however, was found to be too frequent when production rates were low and was energy inefficient. The fixed time cycle required 17 cycles per day and used over 16,000,000 kg of steam per year per line. A lower explosive limit (LEL) meter was placed on the effluent end of the adsorbers to sense hydrocarbon levels and to determine when to actuate the regenerating valving of the solvent recovery unit. This resulted in longer on-line adsorption for the beds, and changed the regeneration cycles to 9 per day per line, thus reducing steam consumption to 7,920,000 kg per year per line or 49.5%. This resulted in an annual savings of 21 x 10^9 Btu's at the current production rate and represents 578 x 10^9 Btu/year at MOB. A gas chromotograph (GC) has been installed at "B" line AC building to automatically determine when the carbon beds should be regenerated.

It was recommended that the preheated air/vapor temperature be reduced to decrease steam consumption and improve the adsorption capacity of the AC. The incoming solvent-laden air was preheated to 43°C (110°F) prior to entering the carbon adsorption beds. Tests were conducted to assess the need for preheating and results showed the following: (a) preheating is unnecessary except in some extremely cold weather, and (b) an appreciable increase in the quantity of solvent recovered is effected by the lower operating temperature. Accordingly, preheating of this solvent-laden air has been discontinued except during cold weather. At MOB, this has resulted in a projected annual steam savings of 73,123 MBtu/year, an increase of 1,491,390 pounds ether/year, and 295,650 pounds alcohol/year due to a more efficient solvent recovery.

Ether Still/Alcohol Rectification

Ether Manufacture

Ethyl alcohol is preheated by steam coils, fed into an ether boiler, and mixed with hot sulfuric acid, where part of the alcohol is converted to ether (fig 22). Vapors generated from this process enter a separator where most of the entrained sulfuric acid is removed. These vapors then enter a caustic scrubber to neutralize residual acid. This caustic solution is maintained at 80°C (176°F) to 85°C (185°F) by means of steam coils. The vapors then enter a steam-heated ether fractionating column where ether is separated from the alcohol and water. Ether vapors are then condensed and the resulting liquid ether is fed into a reflux regulating bottle through an ether product cooler to storage.

Ether layer and water layer both from storage, and the solvents which were recovered by carbon adsorption. are pumped to the ether fractionating column. The recovered solvent passes through steam jackets prior to entering the fractionating column. Processing of these materials continue as for ether manufacture.

The alcohol portion of the solution fed into the fractionating column, condenses, and is then passed through a steam-heated alcohol concentrator column. The alcohol vaporizes in the column and flows to condensers, to a product cooler, and then to storage.

Alcohol Rectification House

Weak alcohol from the dehydration process is preheated by hot alcohol vapors and flows to an exhausting column, heated by 40 pounds of steam. Vaporized alcohol then enters a rectifying column. Upon leaving this column, the vapors are fed into the weak alcohol preheater to a condenser and to strong alcohol storage (fig 23).

Steam Usage

Steam consumption for ether manufacture and alcohol rectification was measured in a single location because of the lack of suitable locations to install the steam monitoring equipment. The quantity of steam used to process quantities of ether and alcohol is shown in table 17. The ratio of steam-used to solvent-processed ranged from 5.32 to 10.10 over a measurement period of four months. This range is the result of the variation in the ratio of ether to alcohol processed.

Solvent Recovery

The Solvent Recovery Area accepts single-base propellants having a high residual solvent content. This propellant is loaded into tanks where inert gas, at a temperature of approximately 54°C (130°F), is circulated through the propellant bed to remove the residual solvents. The configuration of the solvent recovery system is shown in figure 24. These solvent vapors and inert gases are then passed through a condenser where the solvents are recovered. The inert gas is then heated by 5 pound steam and recirculated through the propellant bed at 600 cfm. A blower powered by a 3 hp motor recirculates the inert gas.

As seen in the following tables, an average of 0.017 KWH of power is used to process each kg of M6/155 mm propellant, and an average of 0.41 kg steam is required to maintain the 54°C (130°F) inert gas temperature.

Solvent Recovery Power Usage

Type Propellant	Propellant kg	Propellant lbs	Power used (KWH)	KWH/ kg prop
M6/155 mm	114,307	252,000	1,920	0.017

Solvent Recovery Steam Usage

Type Propellant	Temp* (°C)	Propellant		Steam usage		kg steam/ kg prop
		kg	lbs	kg	lbs	
M6/155 mm	54 + 4	14,288	31,500	5,826	12,844	0.41

A combined solvent recovery, water dry and air dry process has been proposed at RAAP.[12] This process will incorporate energy conservation measures, and its successful completion is expected to result in a significant savings in heat and electrical energies.

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*Solvent recovery cycle - Load temp = 35°C; temp increased to 54°C over 12 hr period; temp maintained at 54°C + 4°C for 40 hrs.

Topping Turbine

The use of a topping turbine to provide steam to the Trinitrotoluene (TNT) Area at reduced pressure, and to generate electrical power in the process, was investigated. Figure 25 shows a schematic of the steam flow to effect this pressure reduction and electrical power generation. Appendix K shows that a steam supply of 425 psia reduced to 20 psia, after passing through a topping turbine, has the potential to generate 989 kw of electrical power. The 20 psia steam is then distributed for use in TNT production.

CONCLUSIONS

This project has identified areas for processing alterations resulting in a total savings of approximately 1,435,000 MBtu/year with immediate processing changes. Additionally, further studies with the potential for approximately 1,449,700 MBtu/year from steam savings and 56,300 MBtu equivalent of electrical power generation, were proposed. Some of these projects have been implemented and others are in various stages of evaluation.

RECOMMENDATIONS

1. Install microprocessors in boiling tub and poacher houses to control and operate the entire process.

2. Install automatic steam valves and temperature controls on all boiling tubs and the poaching tubs (appendix E).

3. Change the fixed time cycle for regeneration of AC beds to a "demand cycle" based on the effluent solvent vapor concentration (ref 10).

4. Extract heat lost through effluent air at open tank air dry buildings to preheat incoming air in drying single-base propellants (ref 12).

5. Evaluate the use of a Rankine Cycle Engine at the inert gas manufacturing plant, oleum plant, AOP, NAC/SAC, and power plants 1 and 2 to generate electricity by using hot waste gases (ref PE-626).

6. Insulate all the new stainless steel boiling tubs and stainless steel poacher tubs to reduce heat now wasted through radiation (ref PE-562).

7. Install a topping turbine in the TNT and Fourth Rolled Powder (including the Continuous Automated Single-Base Line) high pressure steam feedlines to generate electrical power when the steam pressure is reduced (ref appendix K).

REFERENCES

1. "Du Pont Energy Management Services, Study of Radford Army Ammunition Plant" dated 8-12, 22-29, 1975, E. I. du Pont de Nemours and Company, Wilmington, Delaware.

2. A method to recover heat from these hot wastewaters is being evaluated on Project PE-602 "Recovery of Waste Heat from Nitrocellulose Poaching Tubs."

3. Contractor report ARLCD-CR-78012 "Optimum Energy Recovery Systems for Chemical Process Operations "Luedzke and Bozza, August, 1978.

4. Production Engineering Project PE-222 "Establishment of an Improved Process for Purification of Nitrocellulose".

5. PE-548 "Combined Solvent Recovery/Drying of Single-Base Propellant".

6. PE-522 "Recovery of Heat From Effluent Air - Open Tank Air Dry".

7. PE-561 "Modernized FAD for Multibase Propellants".

8. MCA Project

9. "Du Pont Energy Management Services Study of Radford Army Ammunition Plant', dated September 8-22, 22-29, 1975, E. I. du Pont de Nemours and Company, Wilmington, Delaware.

10. "Optimum Energy Recovery Systems for Chemical Process Operations" Edward E. Luedkes, TRW, Eugene F. Bozza, ARRADCOM.

11. "Energy Conservation in Solvent Recovery Operations", PE-602, RAAP, August 1, 1980.

12. PE-631 "Air Tempering with Carbon Bed Vapors", February, 1980.

13. PE-548 "Combined Solvent Removal/Drying of Single-Base Propellants".

Table 1. Electrical measurements - cotton dry house

Date measured	KWH (440 V)	Cotton linters kg	Cotton linters lbs	Pulp kg	Pulp lbs	KWH/ kg cellulose
2/80	9,720	---	---	225,755	497,698	0.043
3/80	7,680	---	---	345,909	762,586	0.023
4/80	8,880	---	---	233,661	515,126	0.038
					$\bar{x}$ =	0.0367
6/80	10,920	126,427	278,726	---	---	0.0864

Table 2. Boiling times for various nitrocellulose types

Treatment	BL-1	BL-4	BL-5	BL-7	P-1	P-5	P-7
				Type NC			
1. Acid boil							
a. Min time (hrs)	40	15	15	20	40	20	20
b. Normal time (hrs)	40	15	15	50	40	50	20
2. 1st neutral boil (hrs)	5	5	5	5	5	5	5
3. 2nd neutral boil (hrs)	5	5	5	5	5	5	5

Table 3. Steam usage data on 14 boiling tubs

Date	Steam kg	Steam lbs	Nitropulp kg	Nitropulp lbs	Nitrocotton kg	Nitrocotton lbs	Actual steam (kg stm/kg NC)[a]	Actual/theoretical[b]
5/77	3,193,290	7,040,000	184,636	407,052	168,690	371,897	9.03	3.38
9/77	888,853	1,959,586	87,689	193,322	77,284	170,381	5.38	2.02
10/77	2,359,695	5,202,236	67,275	148,314	224,670	495,313	8.08	3.03
11/77	3,251,443	7,168,205	95,412	210,348	163,062	359,491	12.58	4.71
12/77	3,331,060	7,343,730	202,738	445,858	123,088	271,362	10.22	3.83
1/78	3,636,280	8,016,625	168,042	370,470	99,126	218,536	13.61	5.10
2/78	3,534,282	7,811,600	187,493	413,352	127,308	280,667	11.23	4.20
3/78	3,366,894	7,422,605	150,493	309,729	148,633	327,674	11.65	4.36
4/78	2,912,396	6,420,626	170,421	375,708	136,690	301,345	9.48	3.55
5/78	2,987,972	6,587,293	163,249	359,896	121,233	267,269	10.50	3.93
8/78	2,350,330	5,181,503	154,694	340,982	113,238	249,643	8.77	3.29
9/78	2,303,269	5,077,753	131,755	290,465	112,418	247,835	9.43	3.53
10/78	3,146,143	6,935,941	179,167	394,989	136,738	301,451	9.98	3.74
1/79	2,168,595	4,780,853	121,699	268,296	94,164	207,593	10.05	3.69
2/79	1,965,445	4,332,992	122,453	269,958	105,925	233,521	8.61	3.23
3/79	1,846,214	4,070,137	169,227	373,075	112,253	247,471	6.56	2.46
4/79	1,832,641	4,040,214	141,668	312,319	87,920	193,827	7.98	2.99
12/79	910,410	2,007,077	68,380	150,750	52,215	115,112	7.55	2.83
1/80	1,317,150	2,903,770	125,250	276,125	68,715	151,488	6.79	2.54
2/80	1,518,249	3,347,110	164,167	361,921	36,893	81,334	7.55	2.83
3/80	1,804,549	3,978,283	149,234	328,999	68,223	150,404	8.30	3.11
4/80	1,680,158	3,704,052	200,553	442,136	61,973	136,625	6.40	2.40
Total	52,305,318		3,205,695		2,440,459		$\bar{x}$ = 9.26	$\bar{x}$ = 3.398

[a] NC represents sum of nitropulp and nitrocotton.

[b] Theoretical steam usage to NC processed (see Appendix D):

Nitrocotton = 2.93
Nitropulp = 2.41
Avg = 2.67

Table 4. Normal steam consumption - manually controlled boiling tub

Cycle No	Type NC	Amount lbs	Time on acid boil, hrs	Steam consumption: Up to boil, lbs 1	2	3	Acid* boil	On boil, lb/hr, 5-hr boils 1	2
1	P-1 pulp	30,000	40	20,939	20,407	24,484	1829	2,101	-
2	P-7 pulp	30,000	20	19,359	17,255	16,259	1829	1,358	1,708
3	FL-1 linters	20,000	40	17,550	17,558	20,638	1829	2.317	2,256
4	BL-7 linters	20,000	50	18,409	16,467	16,241	1829	1,977	1,738
			Avg	19,064	17,922	19,406	1829	1,938	1,901
			Avg on boil consumption =					1,890 lb/hr	(857 kg/hr)

*Average of 1829 lbs/hr based on 15 measurements ranging from 1050 lbs/hr to 3097 lbs/hr

Table 5. Steam measurement during "on-boil" cycle

	Sensor	Time (hrs)	Steam lbs	Used kg	Rate lbs/hr	Rate kg/hr
1.	Single sensor auto control w/o insulation	87	124,078	56,282	1,426	647
2.	Single sensor auto control with insulation	70	75,470	34,233	1,078	489
3.	Manual control with insulation	79.85	123,368	55,960	1,545	701
4.	Dual sensor auto control with insulation	36.7	25,012	11,345	681	309

Table 6. Electrical measurements - boiling tub house

Date	KWH	Nitrocellulose kg	Nitrocellulose lbs		KWH/ kg NC
2/79	1960	136,624	301,199		0.0143
3/79	1274	120,235	265,311		0.0110
				$\bar{x}$ =	0.0127

Table 7. Electrical measurements - beater house

Date	KWH 440 V	KWH 2300 V	Nitrocellulose kg	Nitrocellulose lbs	KWH/kg NC 440 V	KWH/kg NC 2300 V	Total
6/79	13,800	27,440	584,530	1,288,646	0.024	0.047	0.071
11/79	12,600	---	339,887	---	0.037	---	---
12/79	10,920	11,970	279,053	615,196	0.039	0.043	0.082
1/80	---	70,910	405,134	893,153	---	0.175	---
2/80	---	161,210	439,840	969,665	---	0.367	---
3/80	---	140,420	474,108	1,045,211	---	0.296	---
4/80	---	276,010	604,181	1,331,969	---	0.457	---
				x =	0.033	0.2308	

Table 8. Poacher treatment for all types of NC

	Boiling temp, °C	Boiling time, hr	Agitated wash, min	Settling time, min		Drain time, min
				Pulp	Cotton	
Soda boil	96	4	15	60	30	45
Neutral boil	96	2	15	60	30	45
Neutral boil	96	1	15	60	30	45
Neutral boil	96	1	None	60	30	None

Table 9. Steam usage for a poaching operation

Date	Tub mt'l	Steam kg	Steam lbs	NC kg	NC lbs	Actual use (kg steam/ kg NC)	Actual/ theoretical[a]
7/77	SS	695,040	1,532,300	98,888	217,878	4.30	1.72
	Wood			62,689	138,205		
8/77	SS	3,449,207	7,604,200	472,971	1,042,723	4.88	1.95
	Wood			233,246	514,219		
9/77	SS	3,216,197	7,090,500	367,376	809,925	4.91	1.97
	Wood			287,216	633,203		
						$\bar{x}$ = 4.7	1.88

[a] Theoretical steam usage (see appendix F)
Stainless steel tubs = 2.518 kg steam/kg NC
wooden tubs = 2.463 kg steam/kg NC

Table 10. Electrical measurements for poaching and blending operations

Service measured	Potential (volts)	KWH	Nitrocellulose kg	Nitrocellulose lbs	KWH/ kg NC	Remarks
Motors for storage, feed, vacuum, water, and filter pumps[1]	440	5,660	868,281	1,914,199	0.007	See Sta 1, figure 16
Agitator motors[2]	440	5,280	544,707	1,200,854	0.010	See Sta 2, figure 16
Motors for slurry pumps and shaker screens[2]	440	33,840	616,408	1,358,924	0.055	See Sta 3, figure 16
			Total (440 volts)		0.072	
Line shaft motors[1]	2,300	177,918	2,029,396	4,473,977	0.088	See Sta 4, figure 16
			Total (440 and 2300 volts)		0.160	

1/ Poaching operation

2/ Blending operation

Table 11. Steam usage measurement at an open tank air dry

Propellant type	Steam usage kg	Steam usage lbs	Propellant dried kg	Propellant dried lbs	kg steam/ kg prop	Actual/ theoretical[a]
M6/175 mm	6,624	14,603	4,717	10,400	1.40	1.24
M6/155 mm	3,312	7,302	2,359	5,200	1.40	1.24
M6/175 mm	114,984		37,258		3.09	1.90
M6/175 mm	153,420	338,228	30,663	67,599	5.00	3.07
M6/175 mm)	101,399	223,543	23,587	51,999)	3.07	1.88
M6/155 mm)			9,435	20,800)		
BS-NACO	48,034	105,895	13,591	29,963	3.60	2.21
BS-NACO	87,290	31,325	9,435	20,798)	5.29	3.24
M6/155 mm			7,076	15,599)		

[a]Theoretical kg stm/kg propellant = 0.363 (see appendix I)

Table 12. Electrical power usage at an open tank air dry operation

7-1/2 HP induction motor - 440 volts - 300 cfm blower - 63°C air

Date	Type propellant	Propellant kg	Propellant lbs	KWH	KWH/ kg prop
5/80	M6/155 mm	24,767	54,601	600	0.0242
6/80	M6/155 mm	16,511	36,400	390	0.0236
					$\bar{x}$ = 0.0239

Table 13. Forced air dry steam usage

Type Propellant	Steam (kg)	Time Measured (hrs)	Avg Steam Usage (kg/hr)	Drying Cycle (hrs)	Steam Cycle (kg)	Propellant Cycle (kg)	kg Steam/kg Propellant
M26E1 f/152 mm	119,060	258	461	88	40,610	9798	4.15
	98,066	176	557	88	49,033	9798	5.00
	48,817	88	555	88	48,817	9798	4.98
							$\bar{x}$ = 4.71
M30 f/105 mm	29,212	52	562	52	29,212	9798	2.98
	67,008	53	573	53	30,394	9798	3.10
							$\bar{x}$ = 3.04
M30A1 f/155 mm	30,365	84	361	84	30,365	9798	3.10
	89,640	168	534	84	44,820	9798	4.57
							$\bar{x}$ = 3.83
AHH (casting)	56,732	144	394	144	56,732	9798	5.79

Table 14. Steam usage rate for a forced air dry operation

Cycle No		Steam required from ambient to 60°C Total steam (kg)	Time (hrs)	Rate (kg/hr)			Steam used to maintain temperature at 60°C Total steam (kg)	Time (hrs)	Rate (kg/hr)
1		9,264	16	579			63,075	96	657
2		9,702	16	606			65,599	96	683
3		8,090	12	674			27,981	40.5	691
	Avg =	9,019	14.67	619.7	Avg	=	52,218	77.5	677

Table 15. Electrical power usage at a forced air dry operation

Type Propellant	Propellant kg	Propellant lbs	Power used (KWH)	KWH/ kg prop
M31A1, M30, M735	29,393	64,800	2,040	0. 069

Table 16. Steam usage measurement at a rolled powder operation

Date	Type propellant	Steam kg	Steam lbs	Propellant kg	Propellant lbs	kg steam/ kg prop
1/79	M36A1/4.2" mortar	1,345,769	2,966,863	42,109	92,833	31.96
4/79	N5/MK 43 M36A1/4.2" mortar	1,104,703	2,435,412	13,608 11,341	30,000) 25,002)	44.28
5/79	M36A1/4.2" N5/MK 43	1,023,147	2,255,615	24,902 15,676	54,899 34,559	25.21
6/79	M8/4.2" N5/MK 43	1,046,996	2,308,192	10,796 11,549	23,801) 25,461)	46.86
7/79	M8/4.2" N5/MK 43	881,213	1,942,709	10,796 20,350	23,801) 44,863)	28.29
8/79	M8/4.2" N5/MK 43	845,544	1,864,071	28,123 17,236	61,999) 37,998)	18.64
9/79	M8/4.2" N5/MK 43	858,041	1,891,374	18,379 23,569	40,518) 51,960)	20.41
10/79	M8/4.2" N5/MK 43	856,000	1,887,125	12,837 12,701	28,300) 28,000)	33.52
11/79	M8/4.2" N5/MK 43	986,971	217,586	19,958 8,383	43,999) 18,481)	34.83
12/79	M8/4.2" N5/MK 43	893,661	1,970,152	19,958 8,346	43,999) 18,399)	31.57
					Avg =	31.56

Table 17. Steam usage at an ether still and alcohol rectification house

Steam		Solvents				
		Ether		Alcohol		
kg	lbs	kg	lbs	kg	lbs	kg steam/ kg solvent
2,251,612	4,963,871	111,221	245,196	111,519	245,854	10.10
3,707,034	8,172,474	114,618	252,685	581,693	1,282,391	5.32
4,854,534	10,702,235	173,026	381,451	673,119	1,483,950	5.74

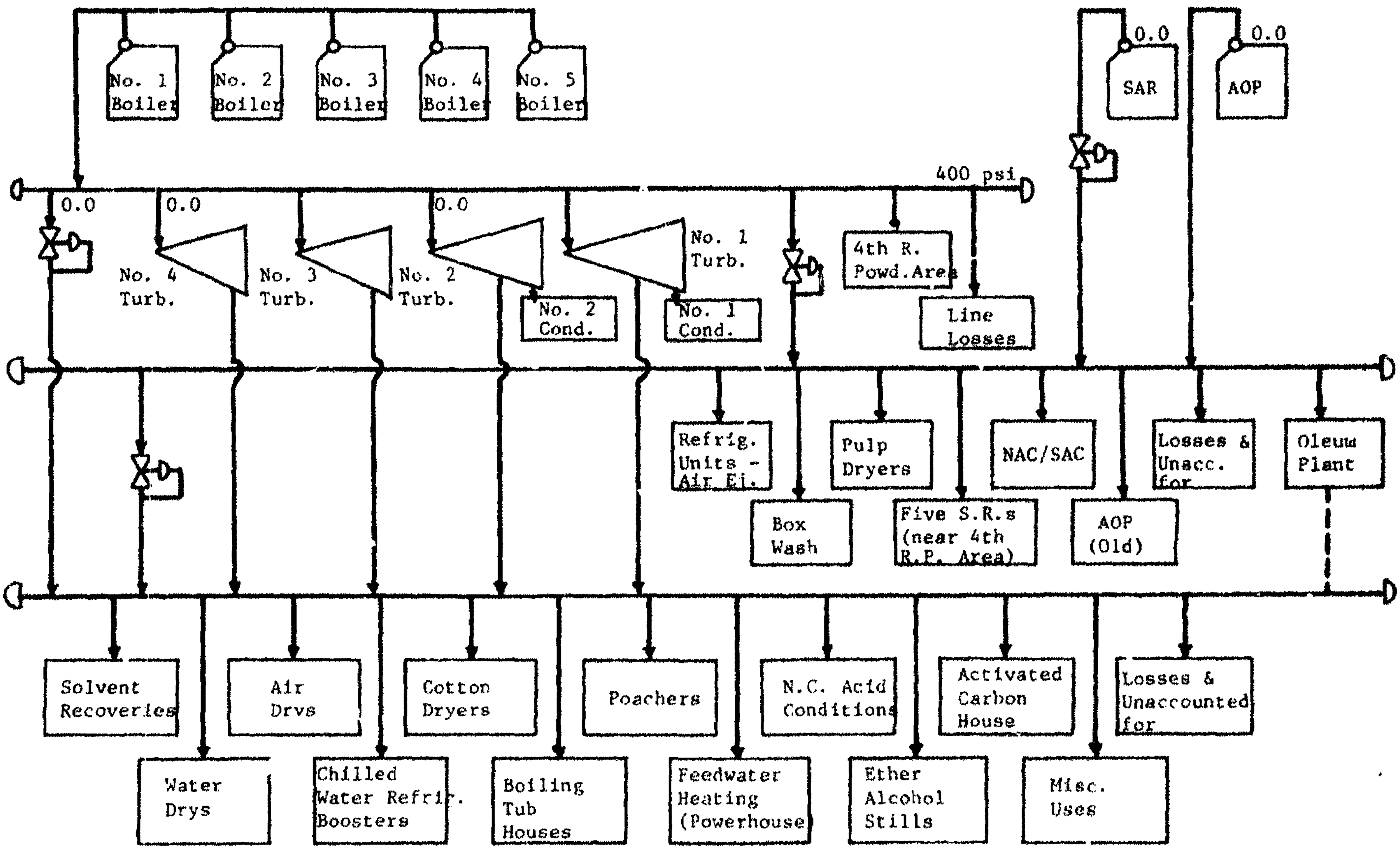

Figure 1. Schematic of steam flow

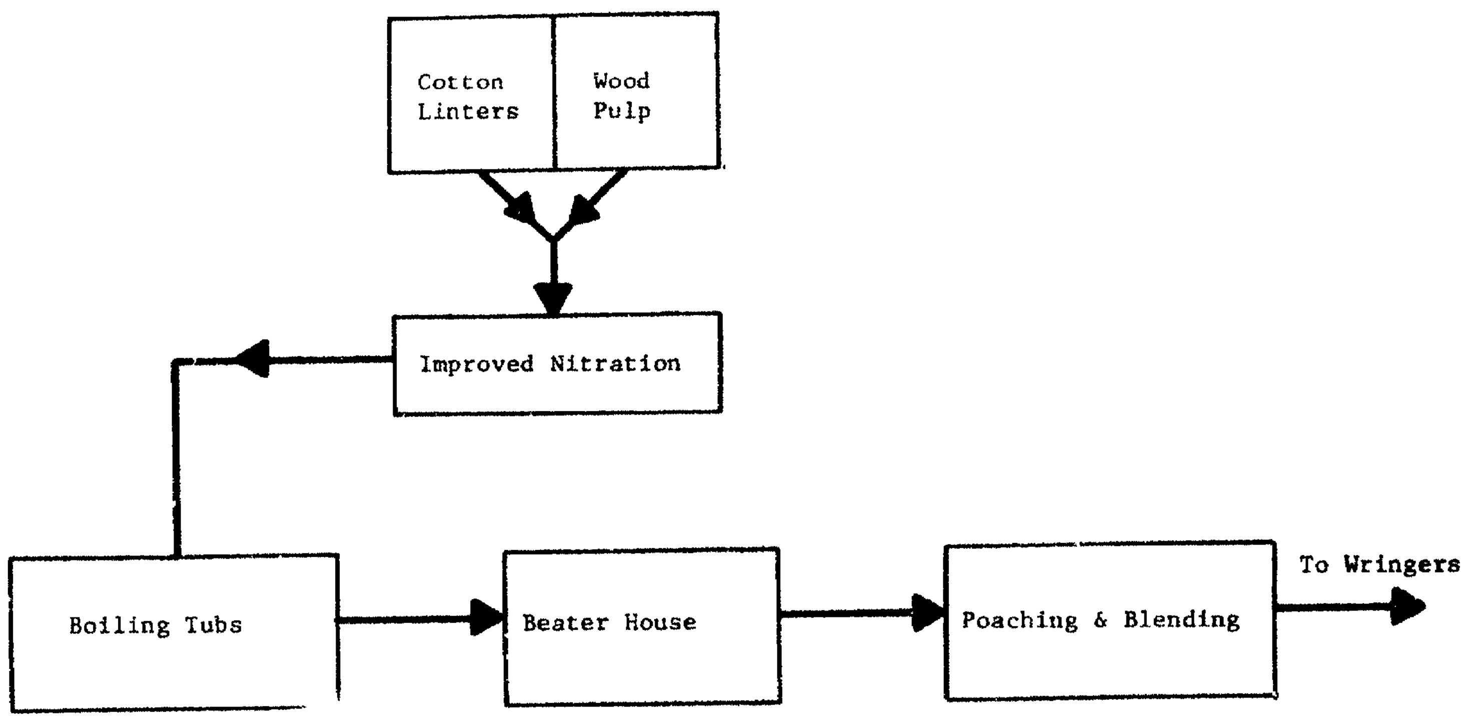

Figure 2. Flow diagram of NC nitration and purification

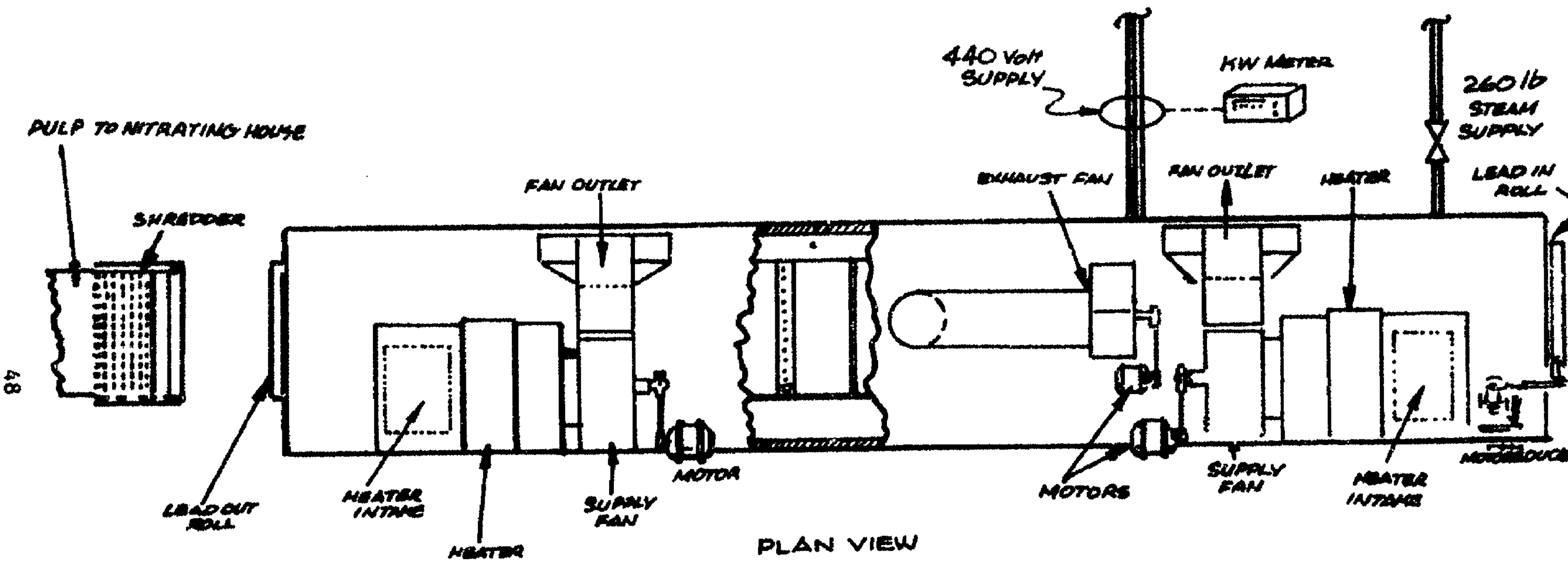

Figure 3. Pulp dryer - steam and electrical

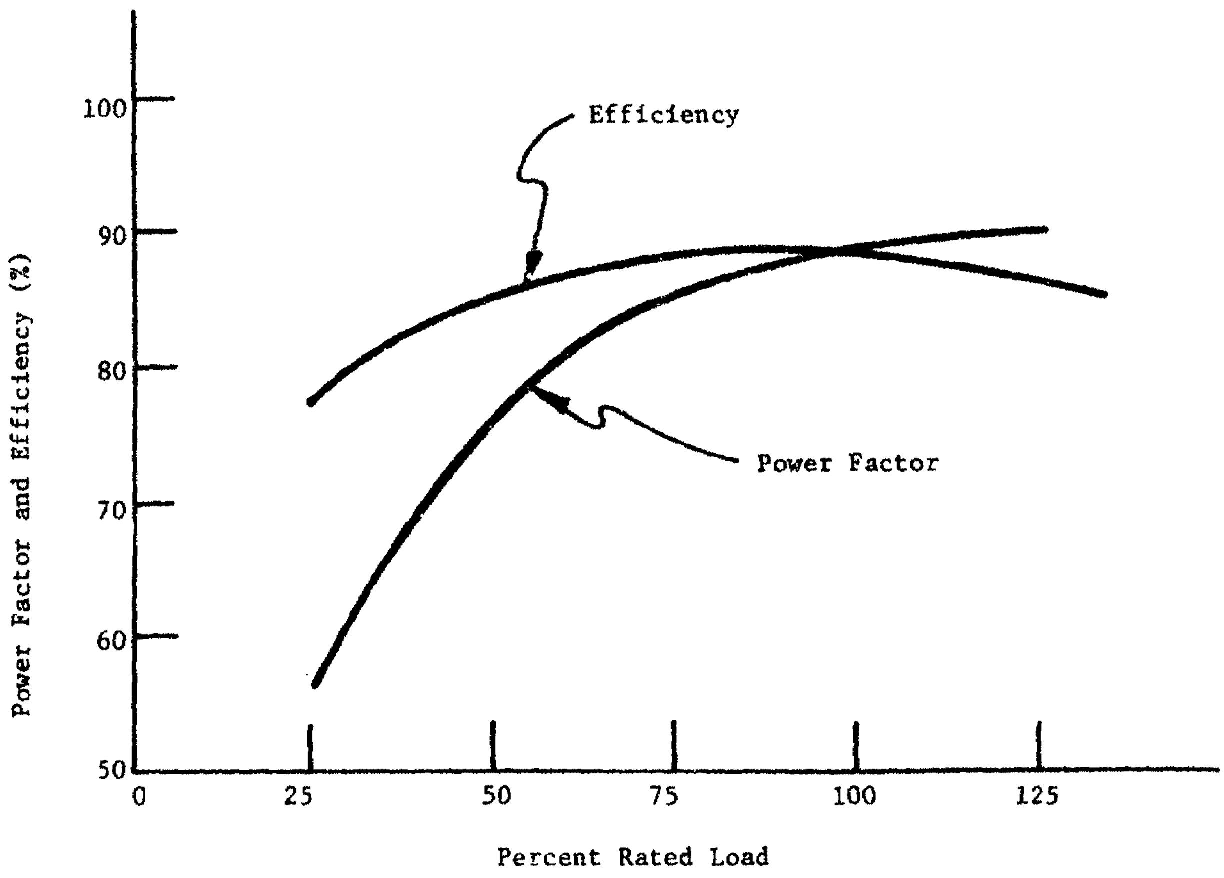

Figure 4. Variation of power factor and efficiency with load for typical induction motor

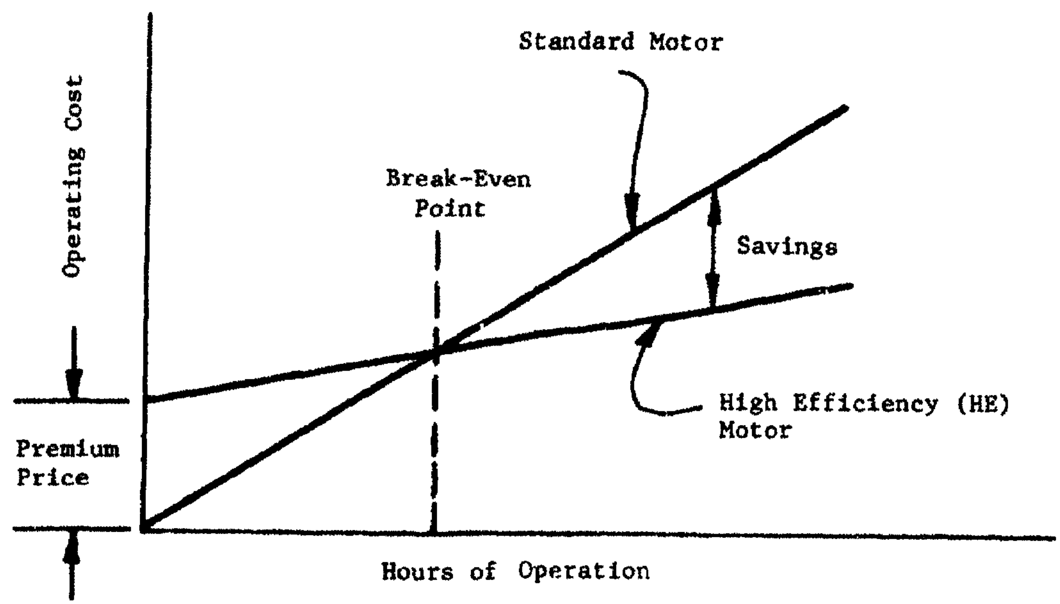

Figure 5. Operating cost comparison, standard versus HE motor

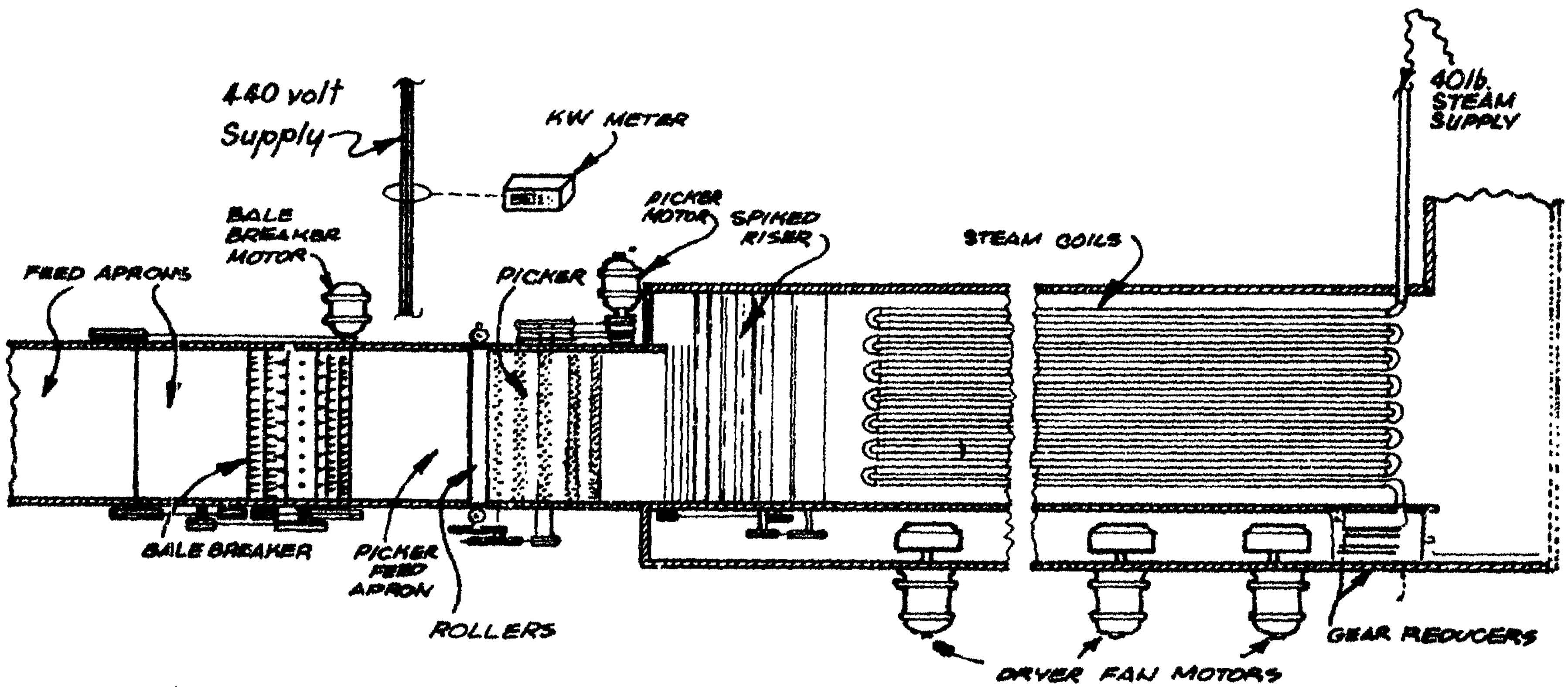

Figure 6. Cotton linters dryer - steam and electrical

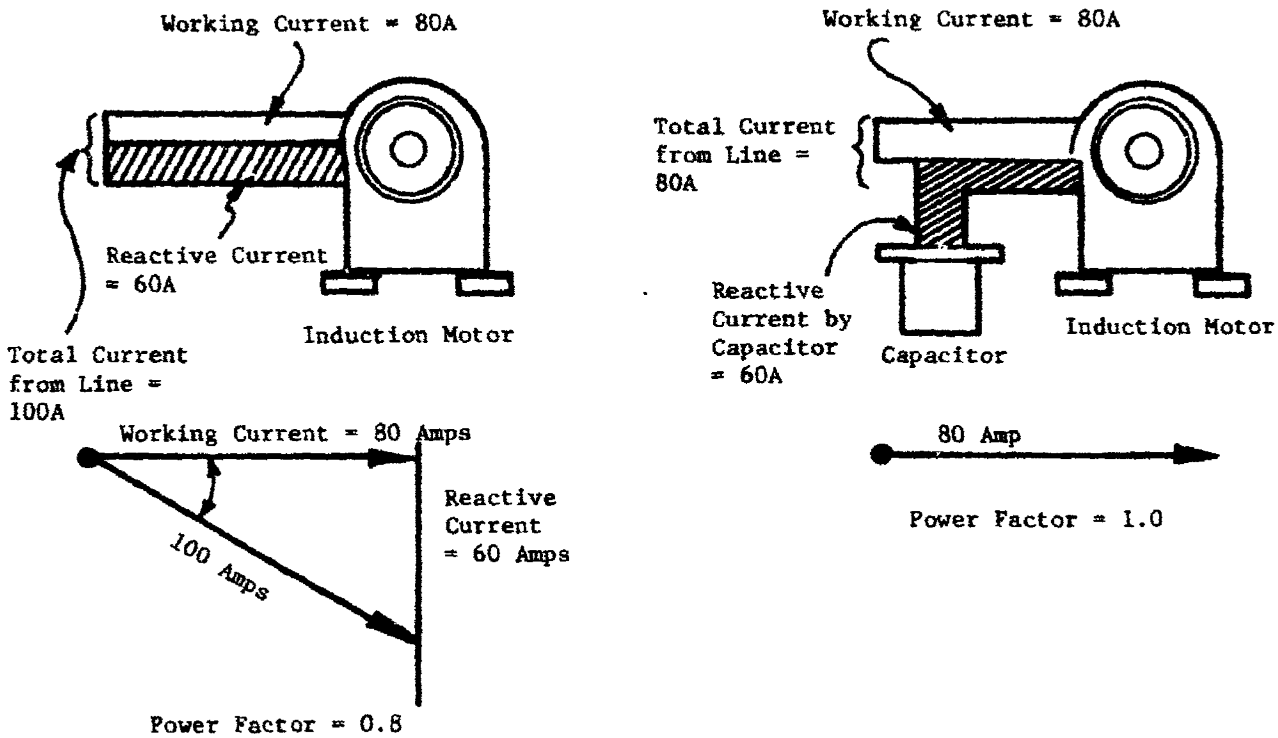

Figure 7. Typical capacitor installation to improve motor power factor

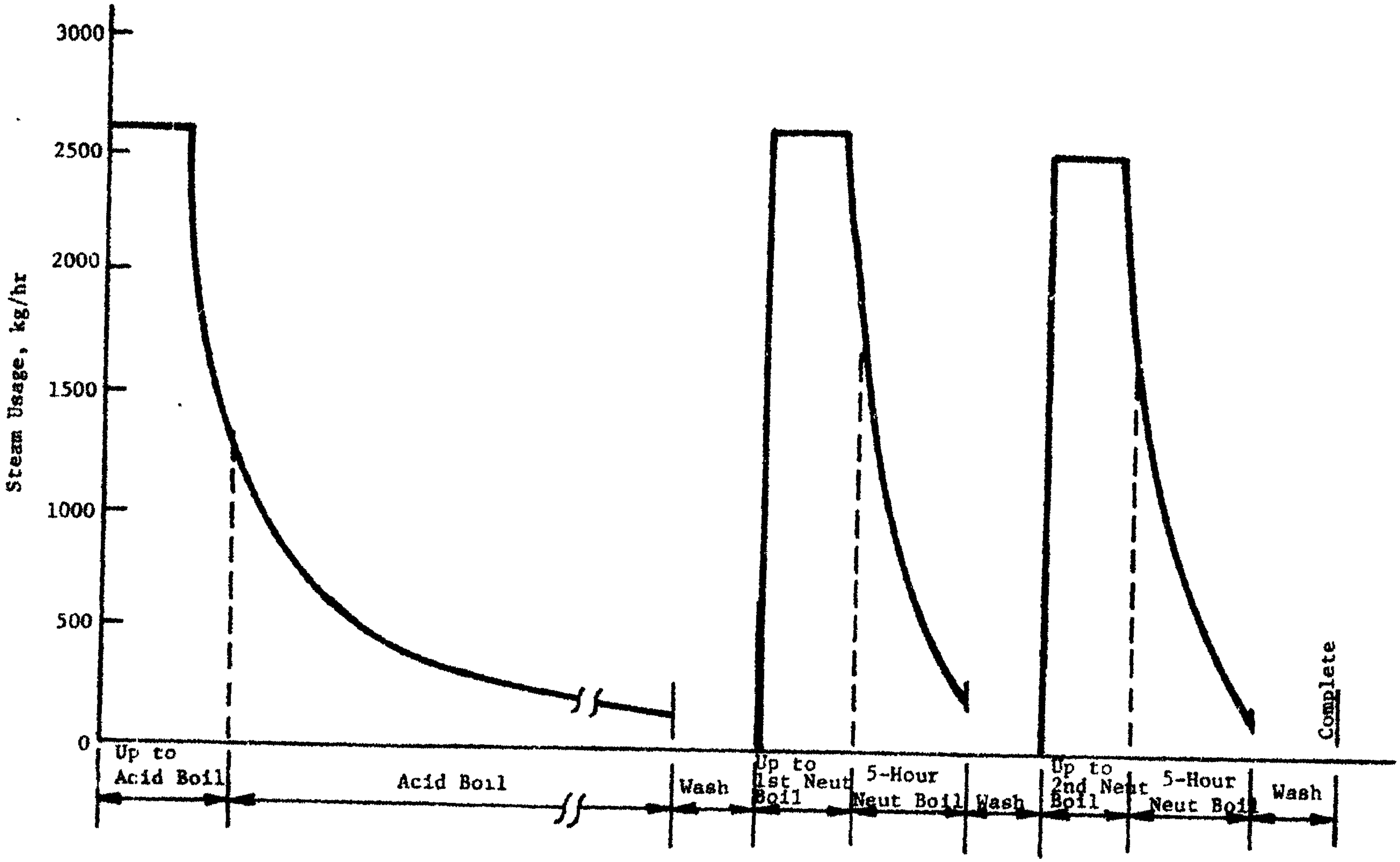

Figure 8. Typical steam usage rate for a boiling tub

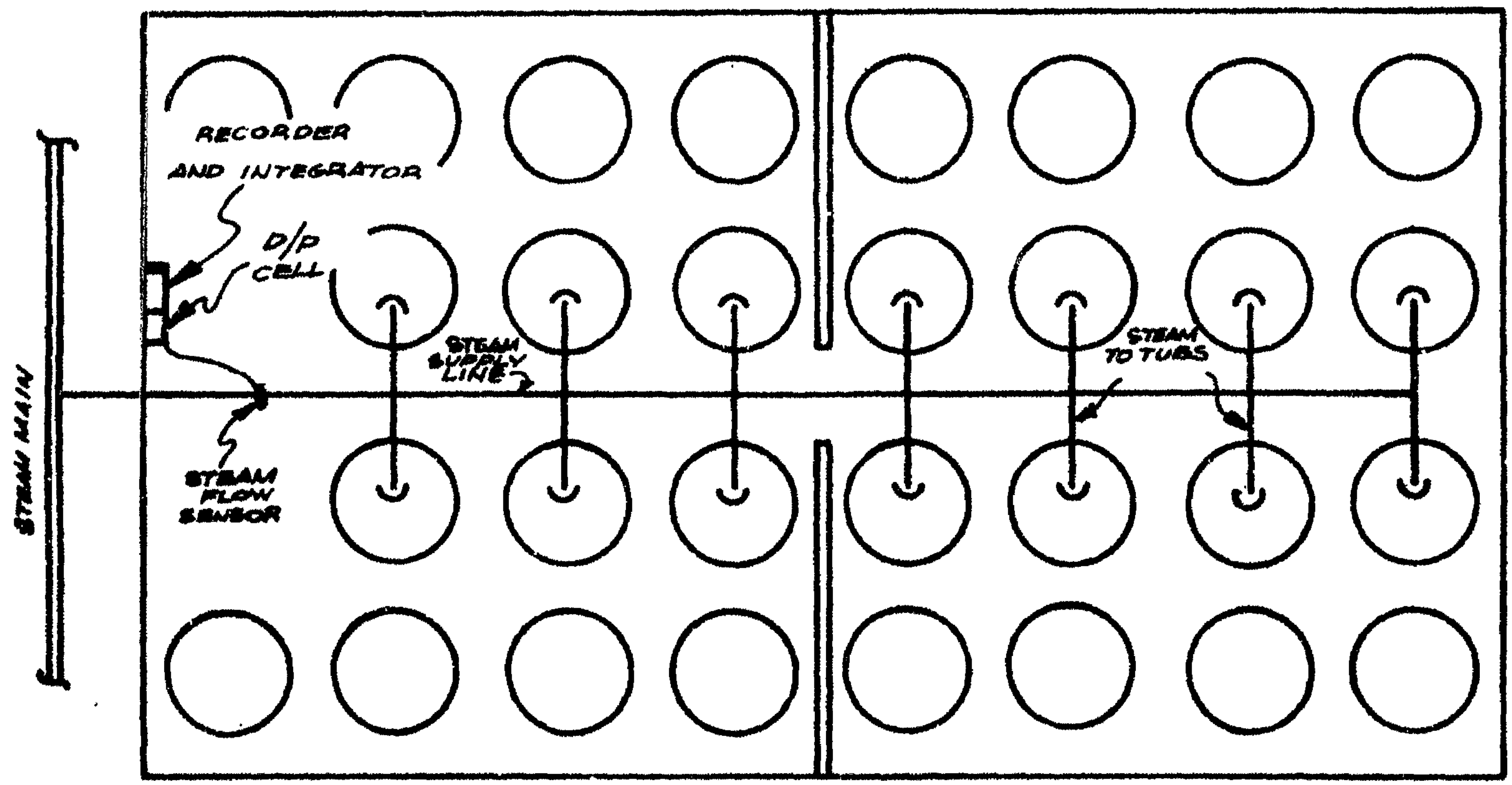

Figure 9. Schematic of boiling tub house measurements - 14 tubs

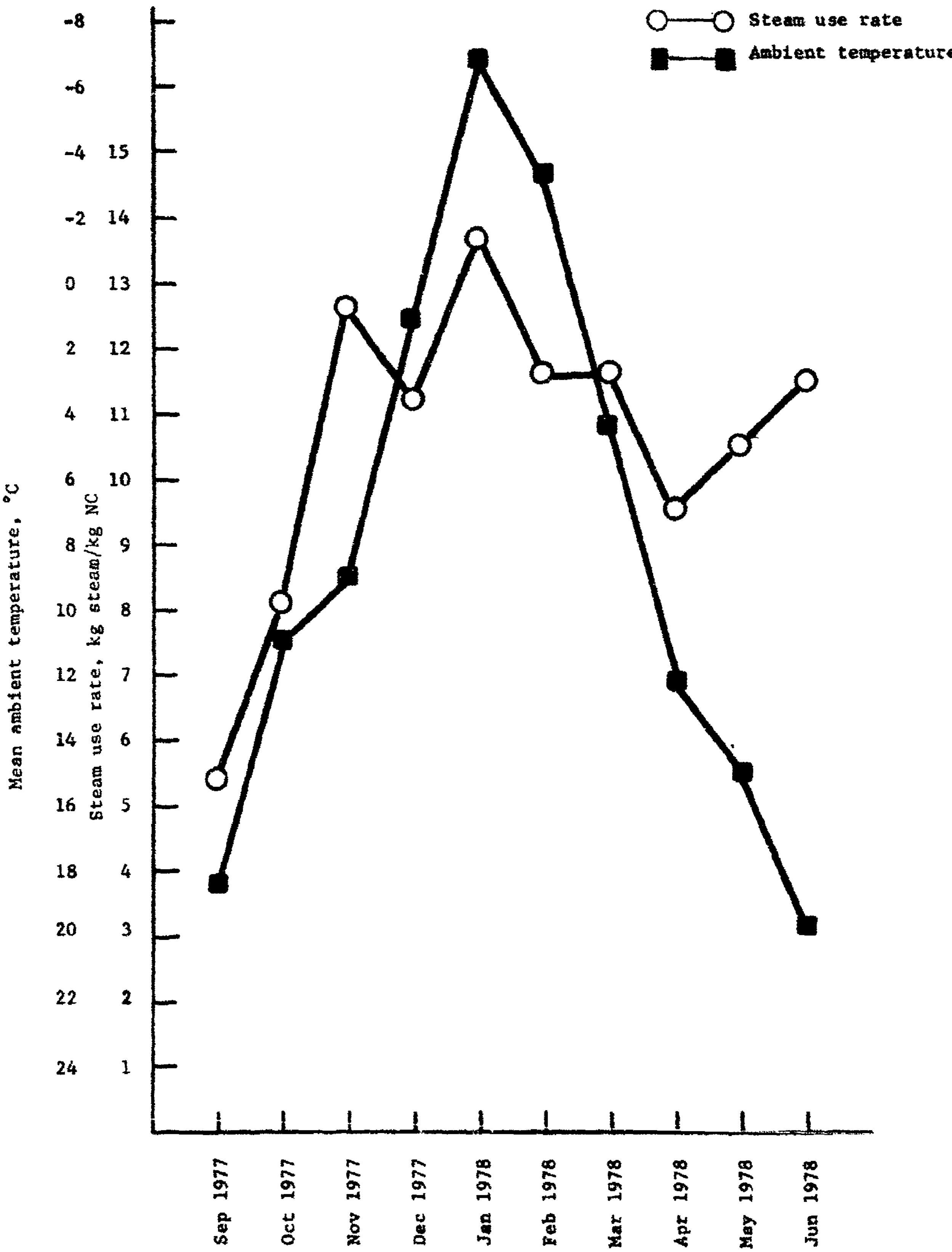

Figure 10. Steam to NC ratio versus time

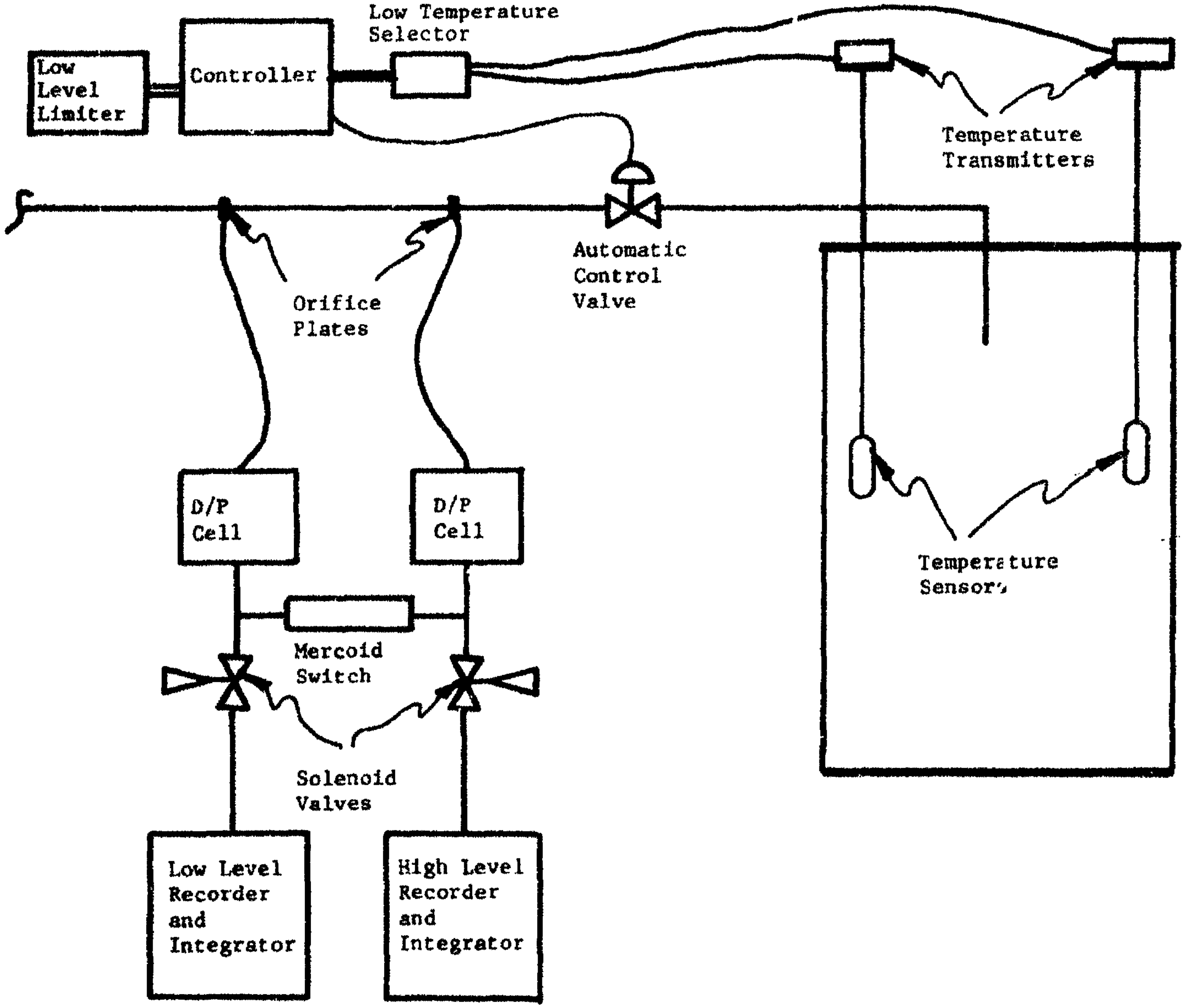

Figure 11. Schematic for steam monitoring and control of a single boiling tub

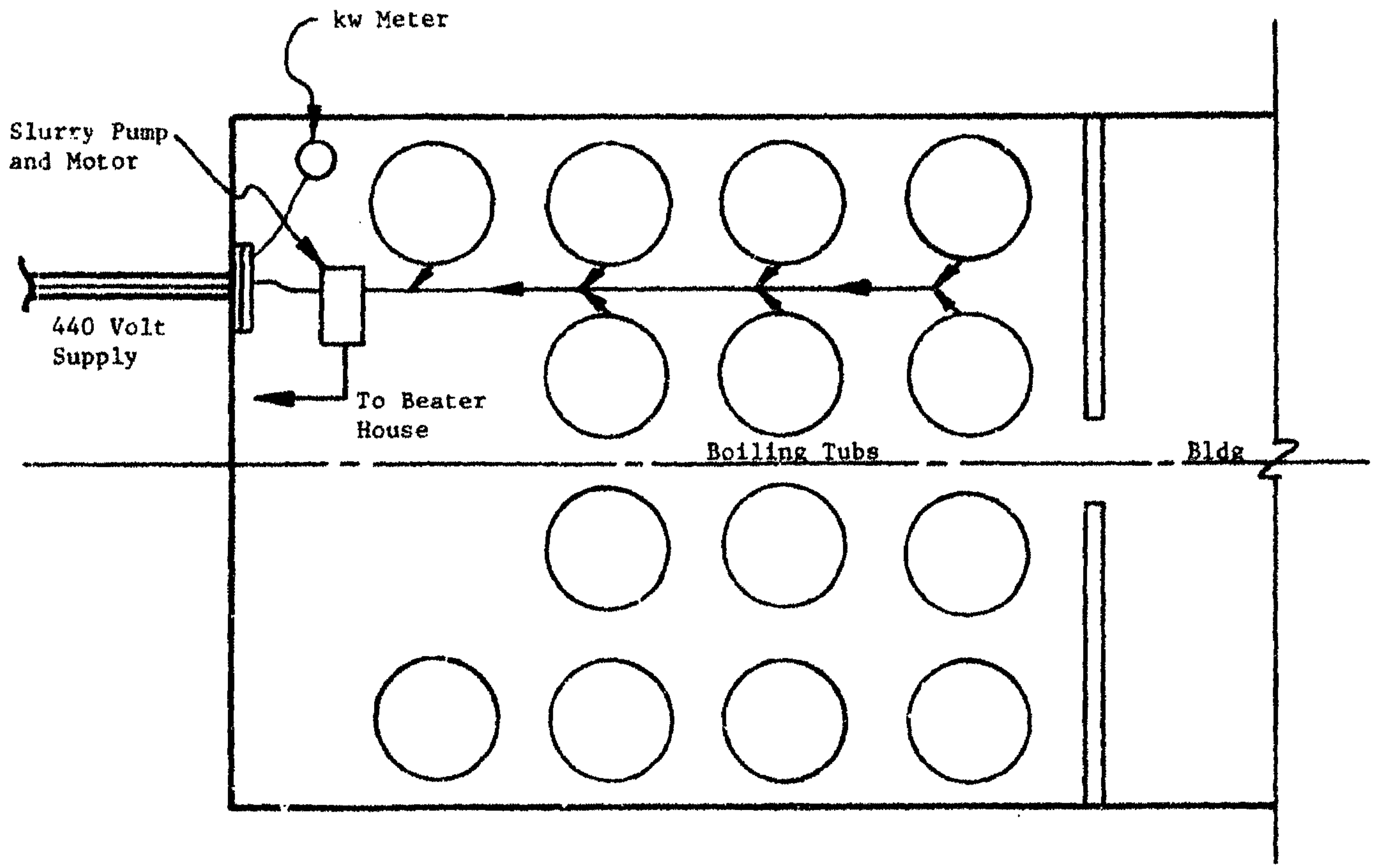

Figure 12. Arrangement for electrical monitoring - boiling tub house

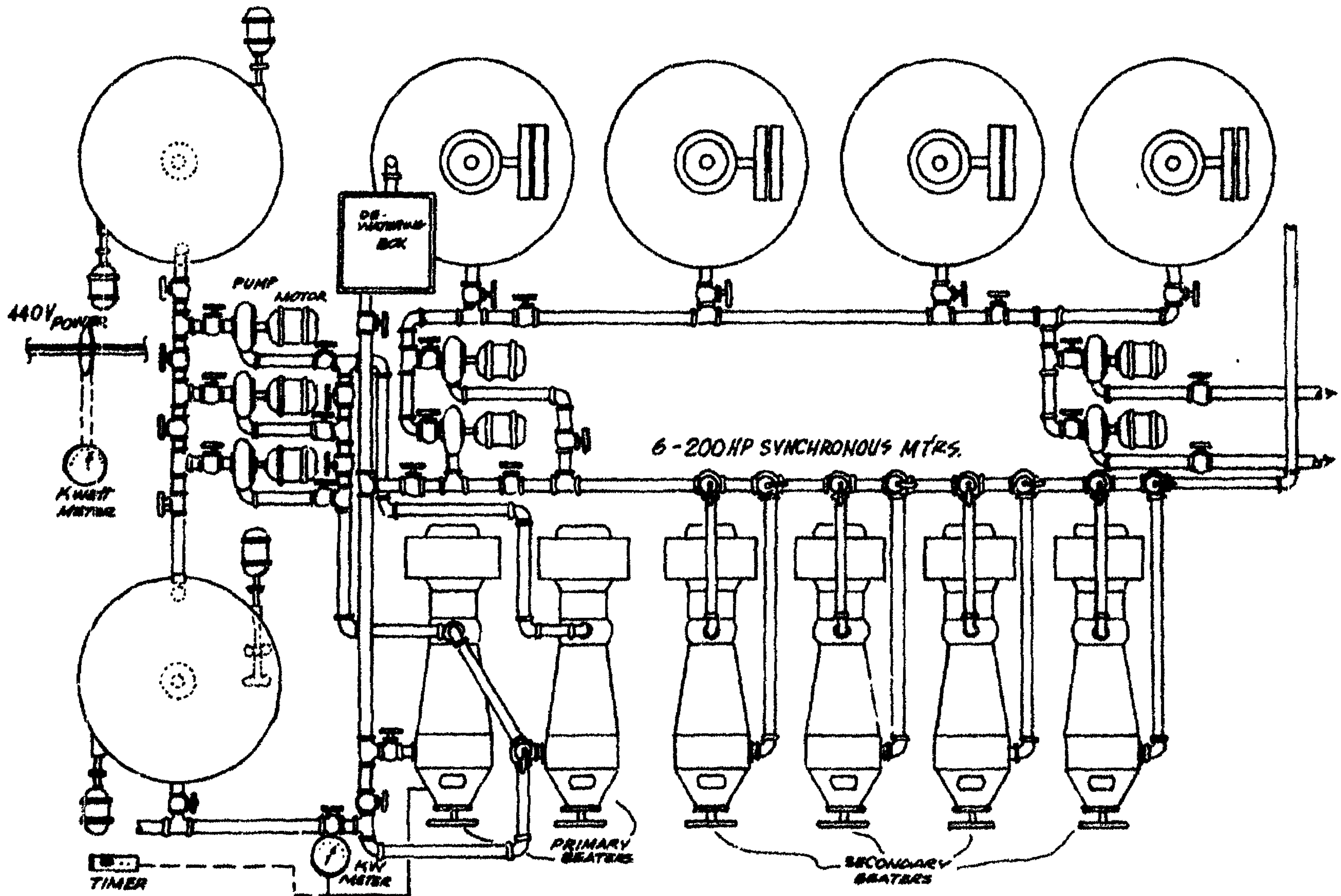

Figure 13. Jordan beater house

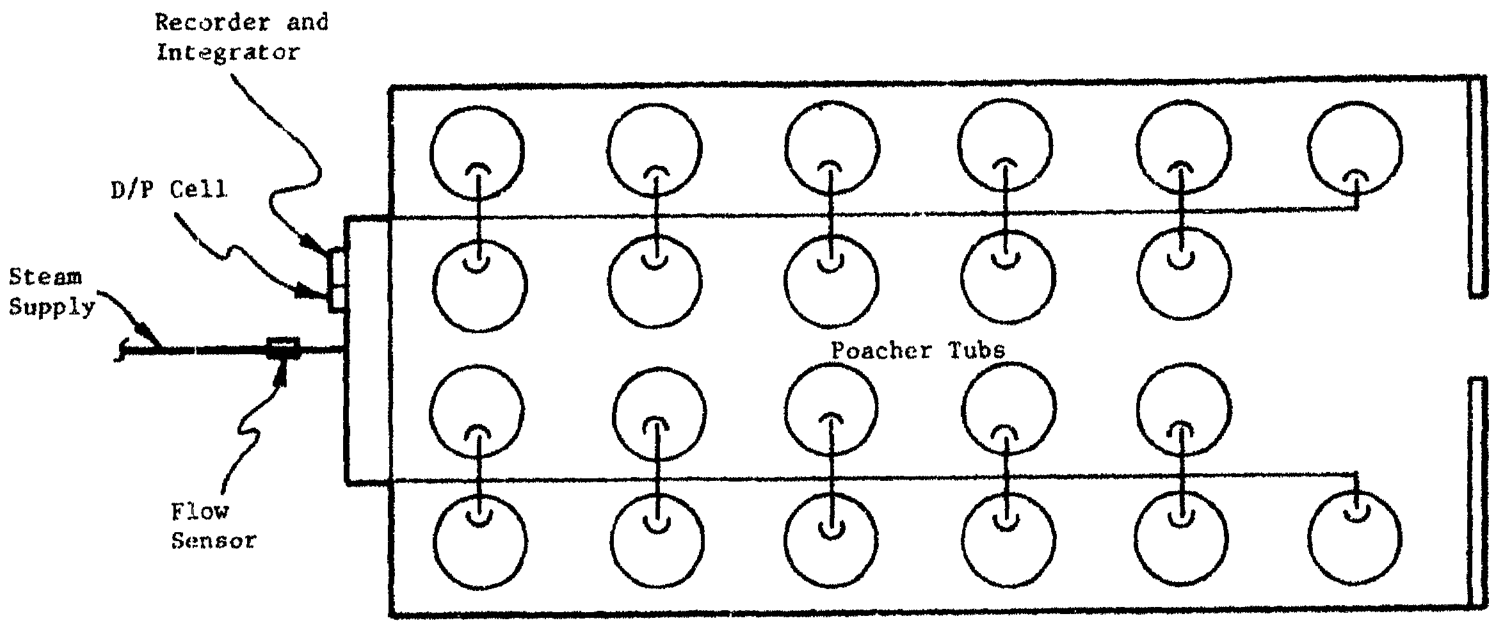

Figure 14. Schematic of steam usage measurements for a poacher tub house

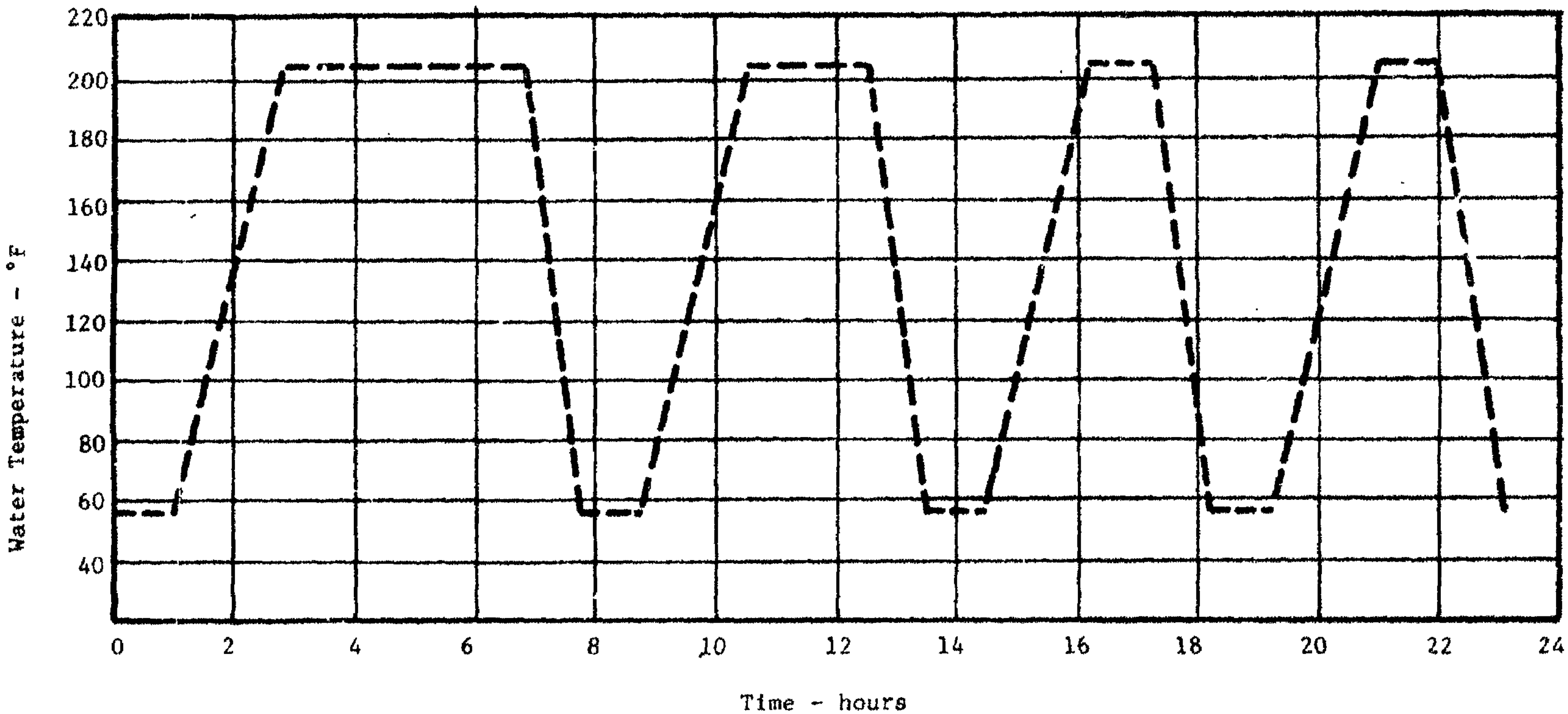

Figure 15. Idealized poacher cycle

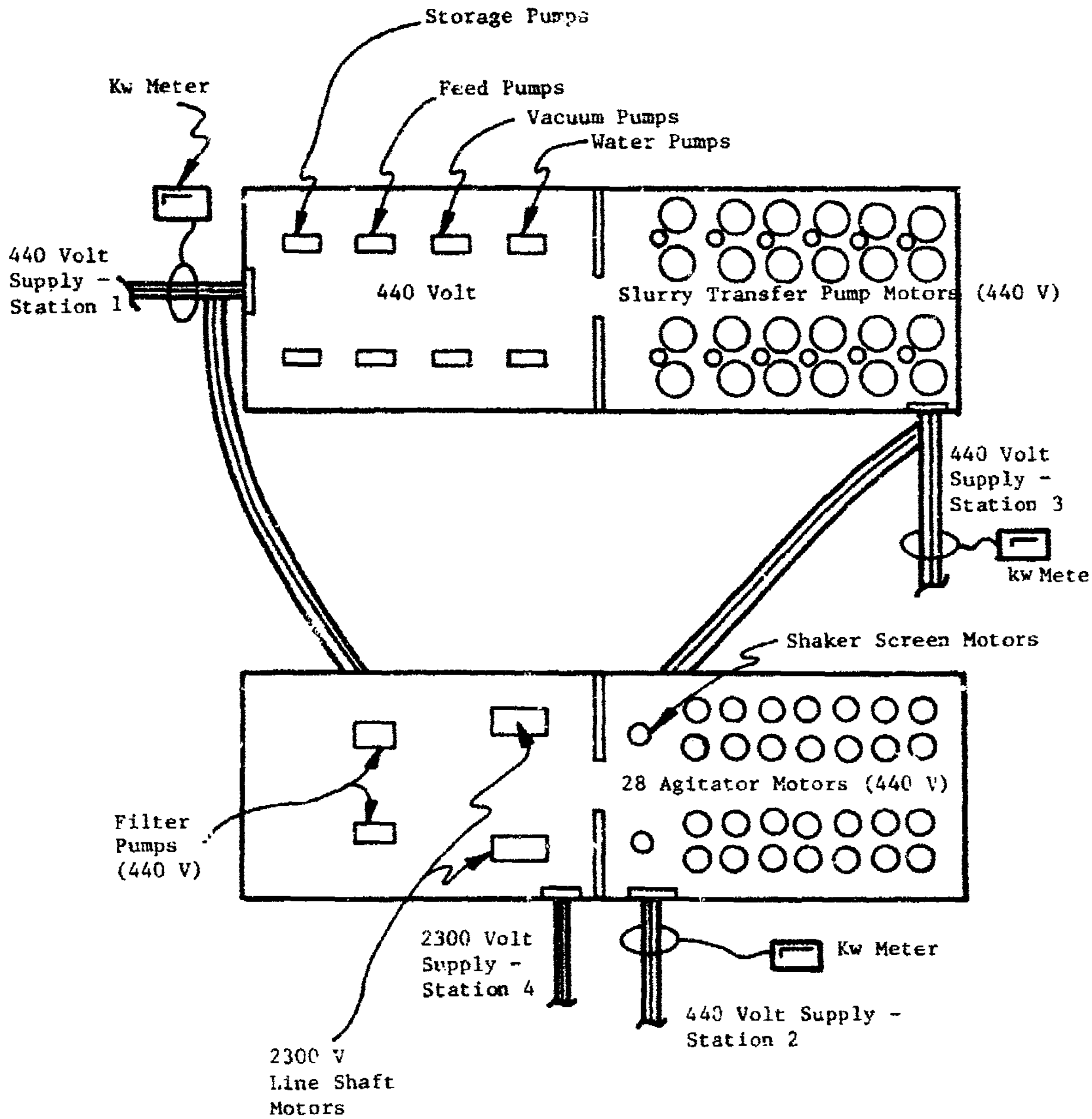

Figure 16. Arrangement of motors in poaching and blending operations

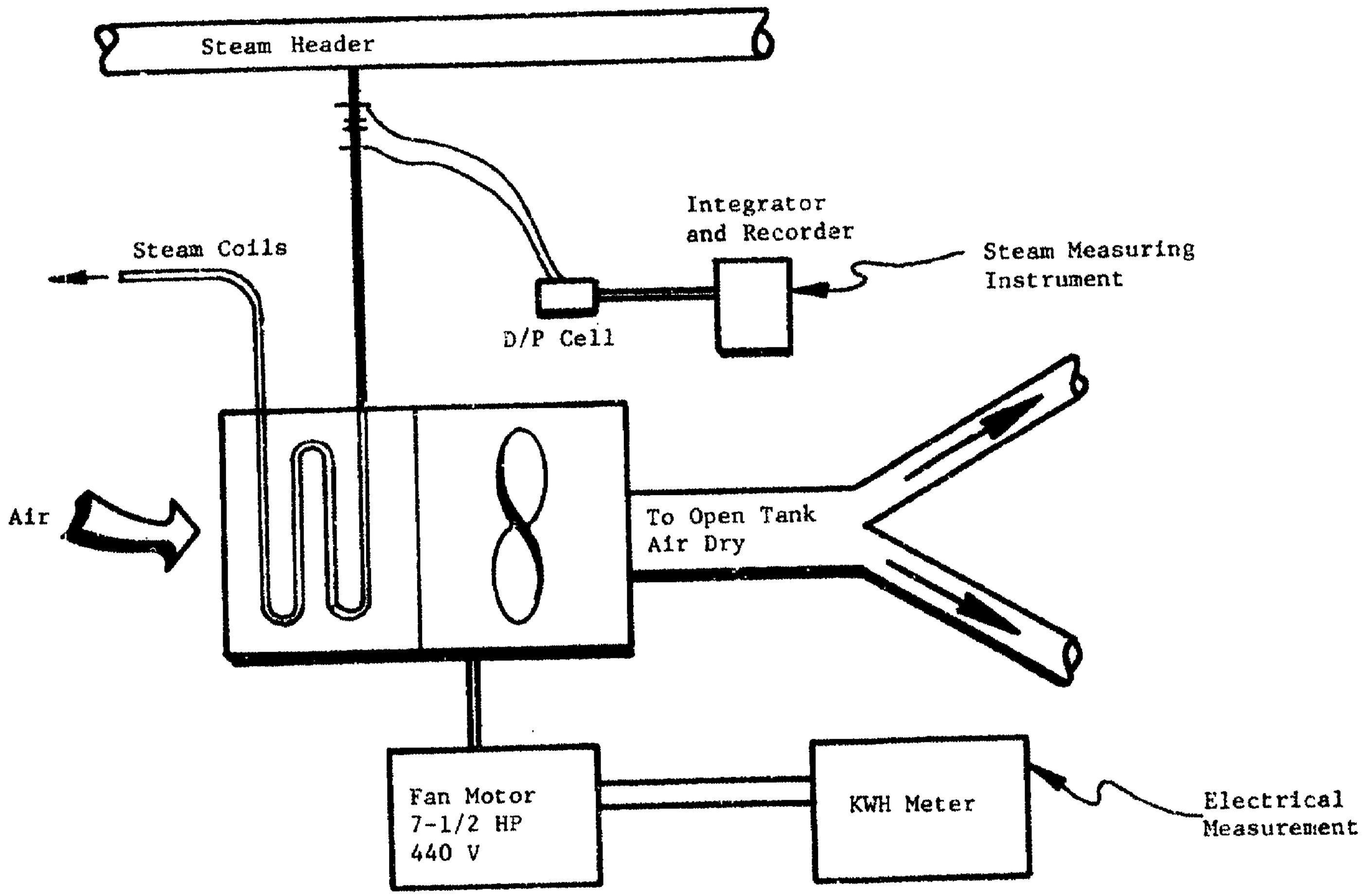

Figure 17. Schematic of steam and electrical measurements at an open tank air dry building (one tank)

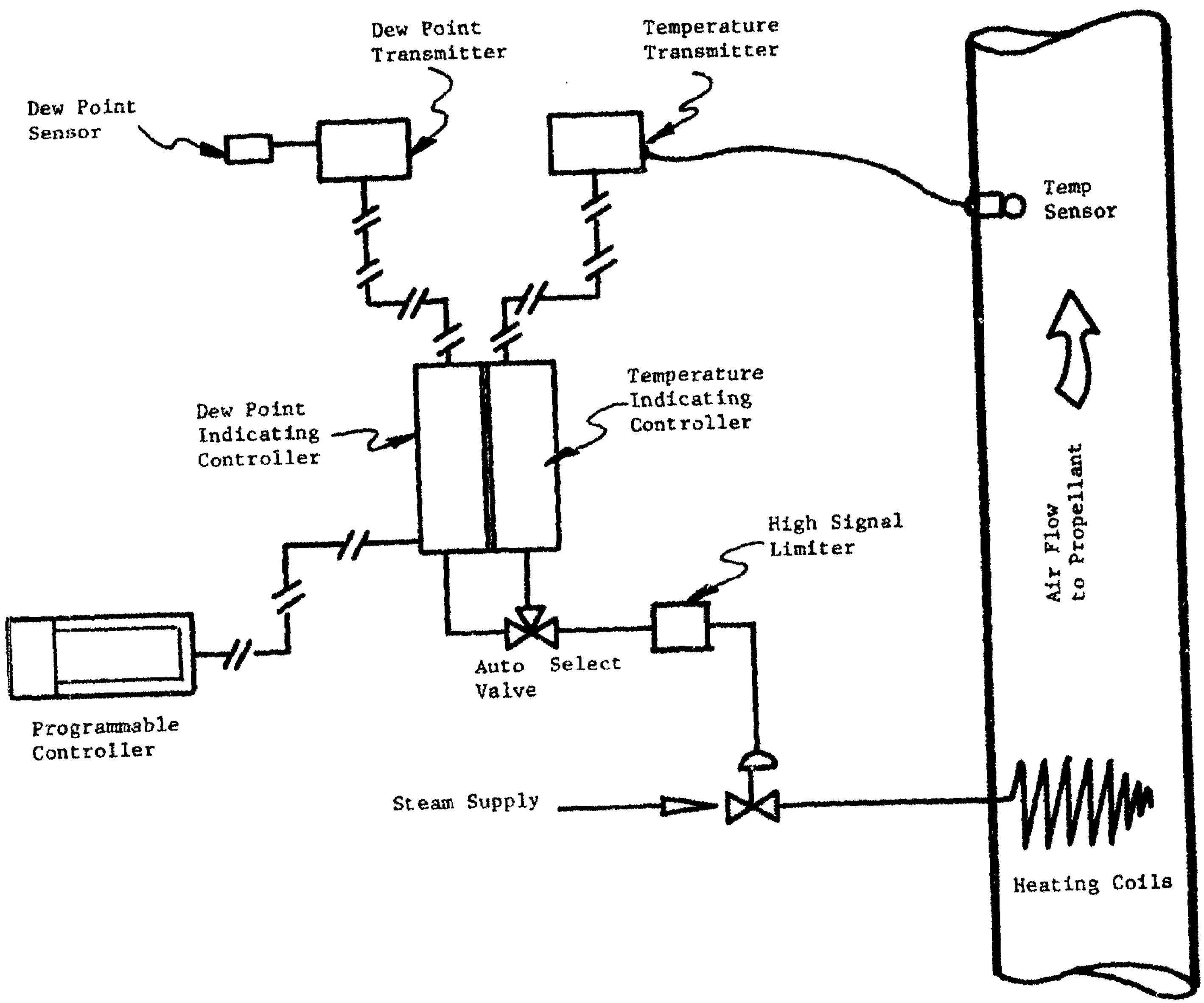

Figure 18. Method to maximize use of outside air at open tank air dry

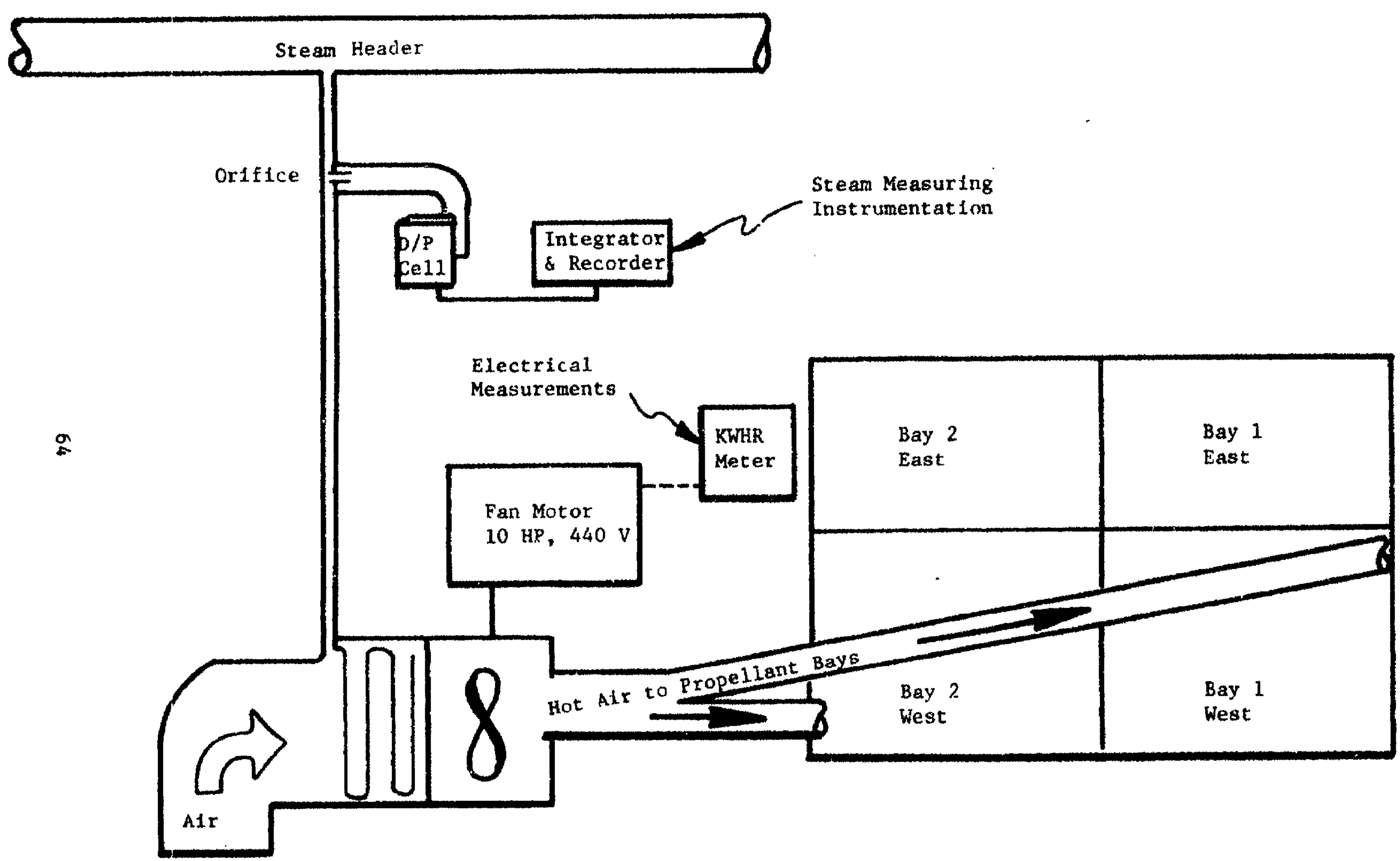

Figure 19. Schematic of steam and electrical measurements at a forced air dry building

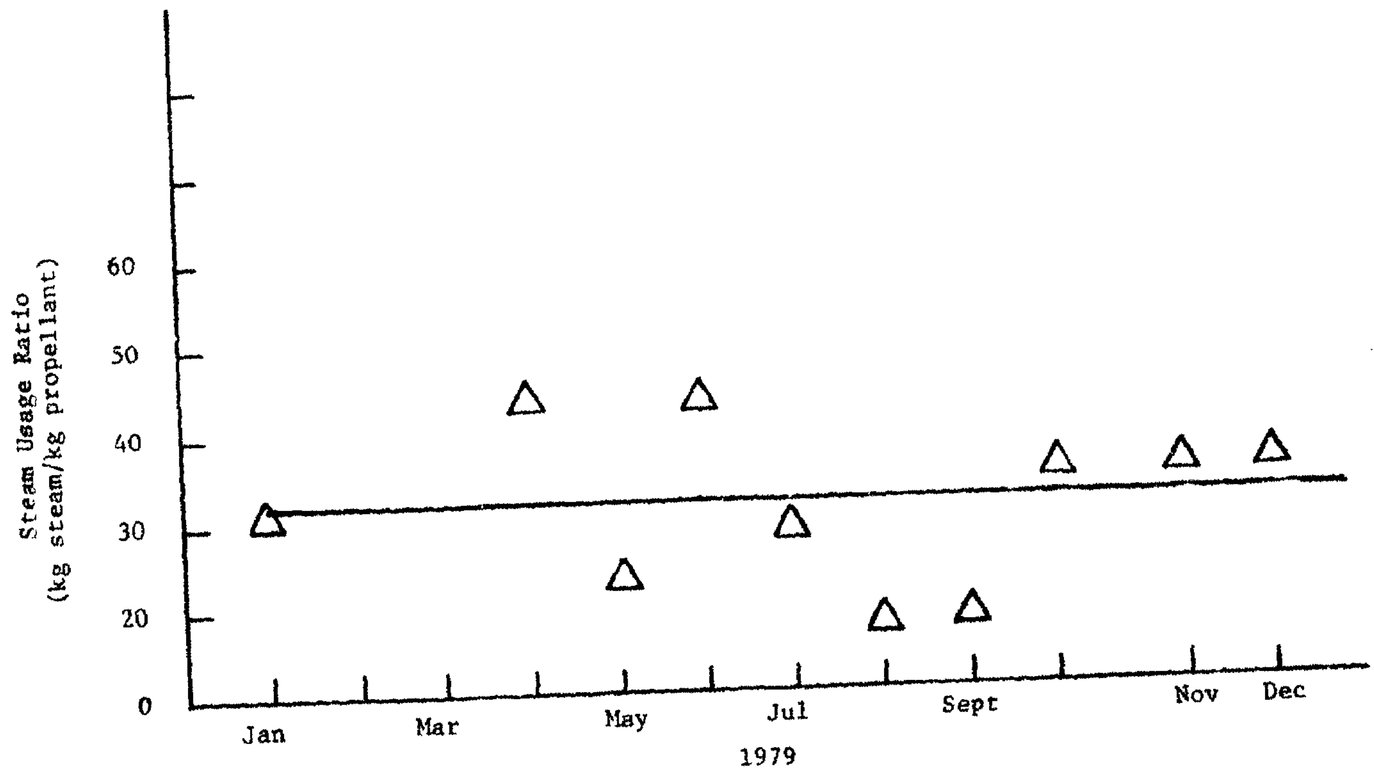

Figure 20. Steam usage measurements at a rolled powder building

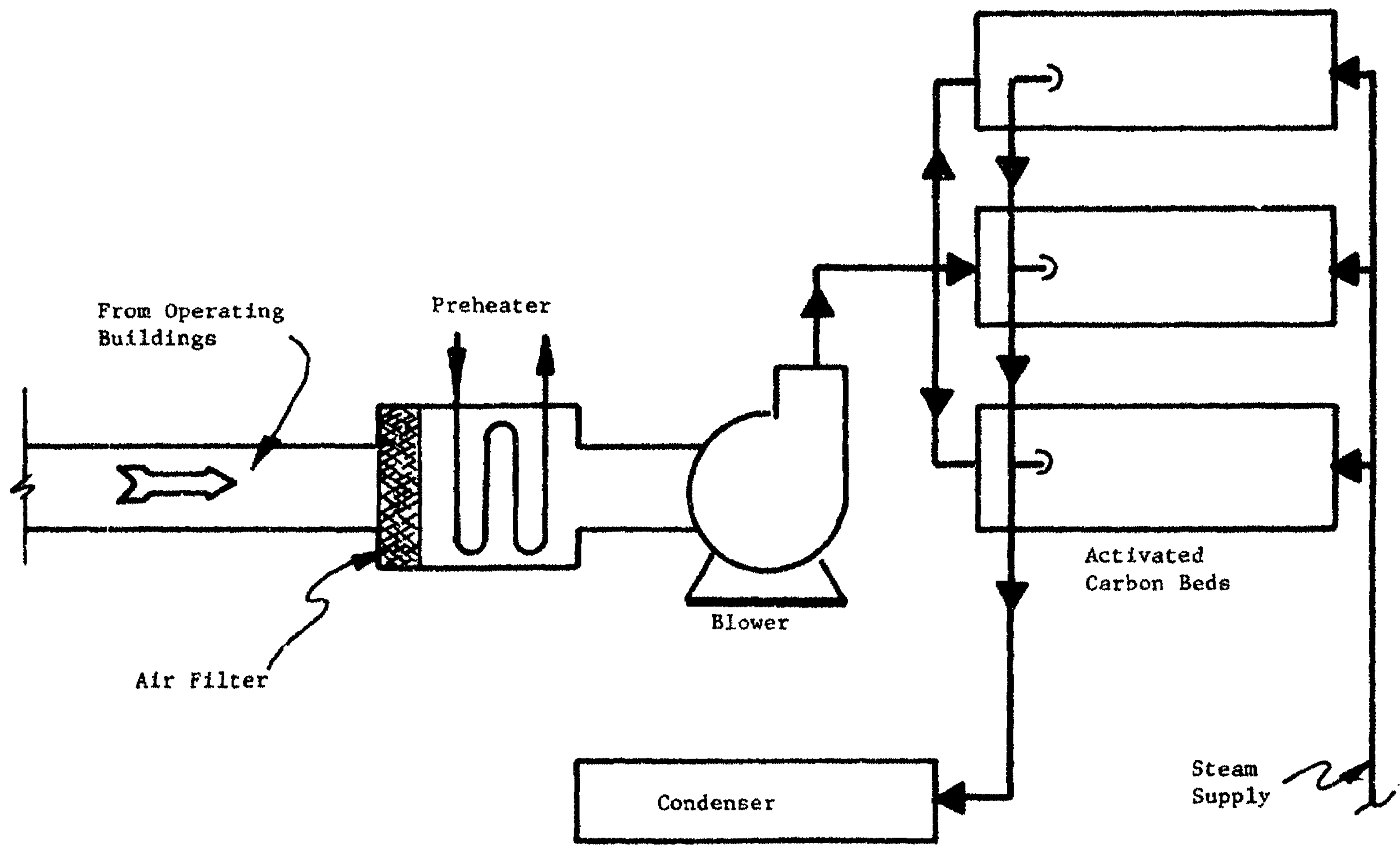

Figure 21. Schematic of an activated carbon solvent recovery operation

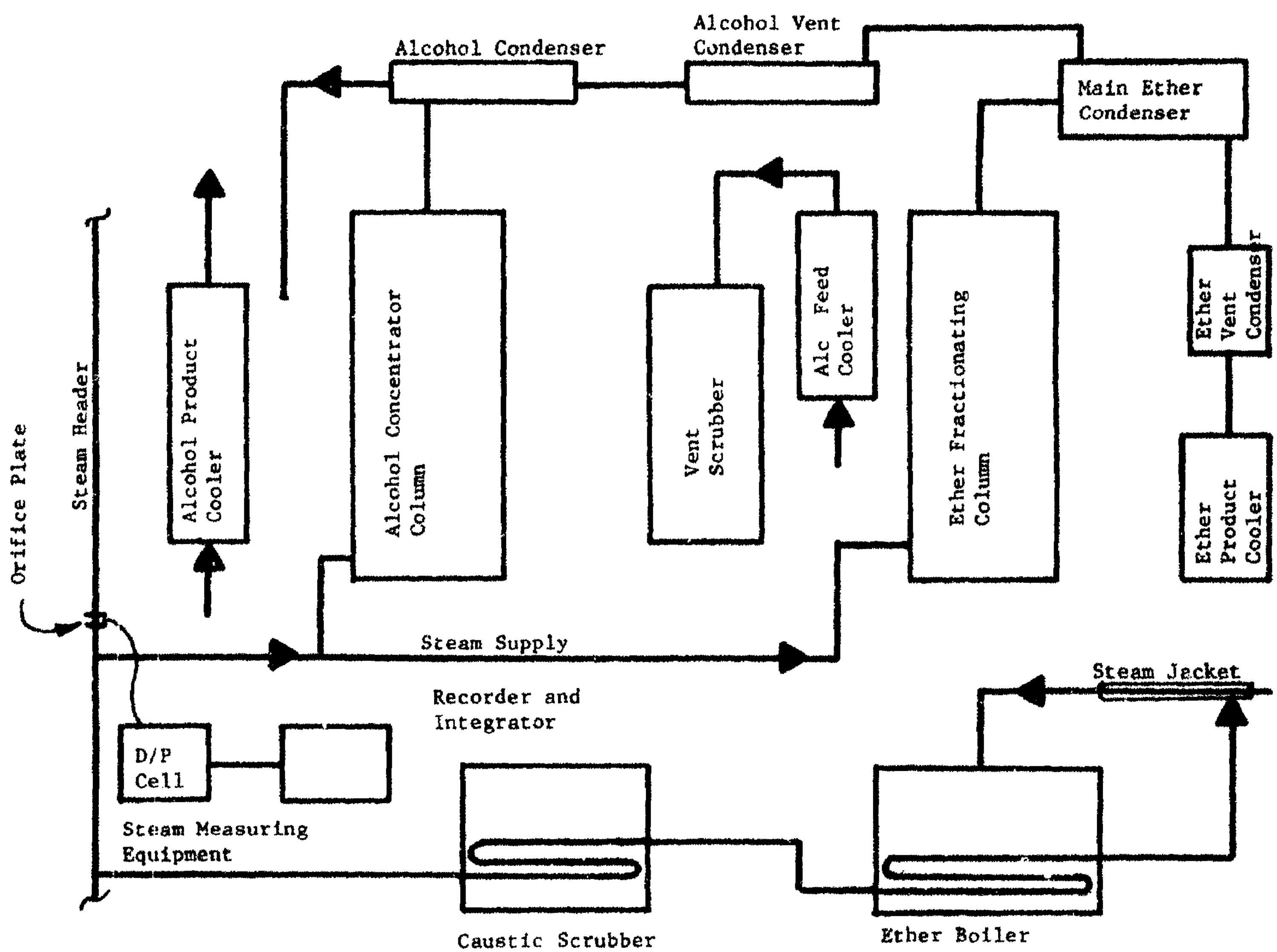

Figure 22. Schematic of ether manufacture and alcohol rectification unit

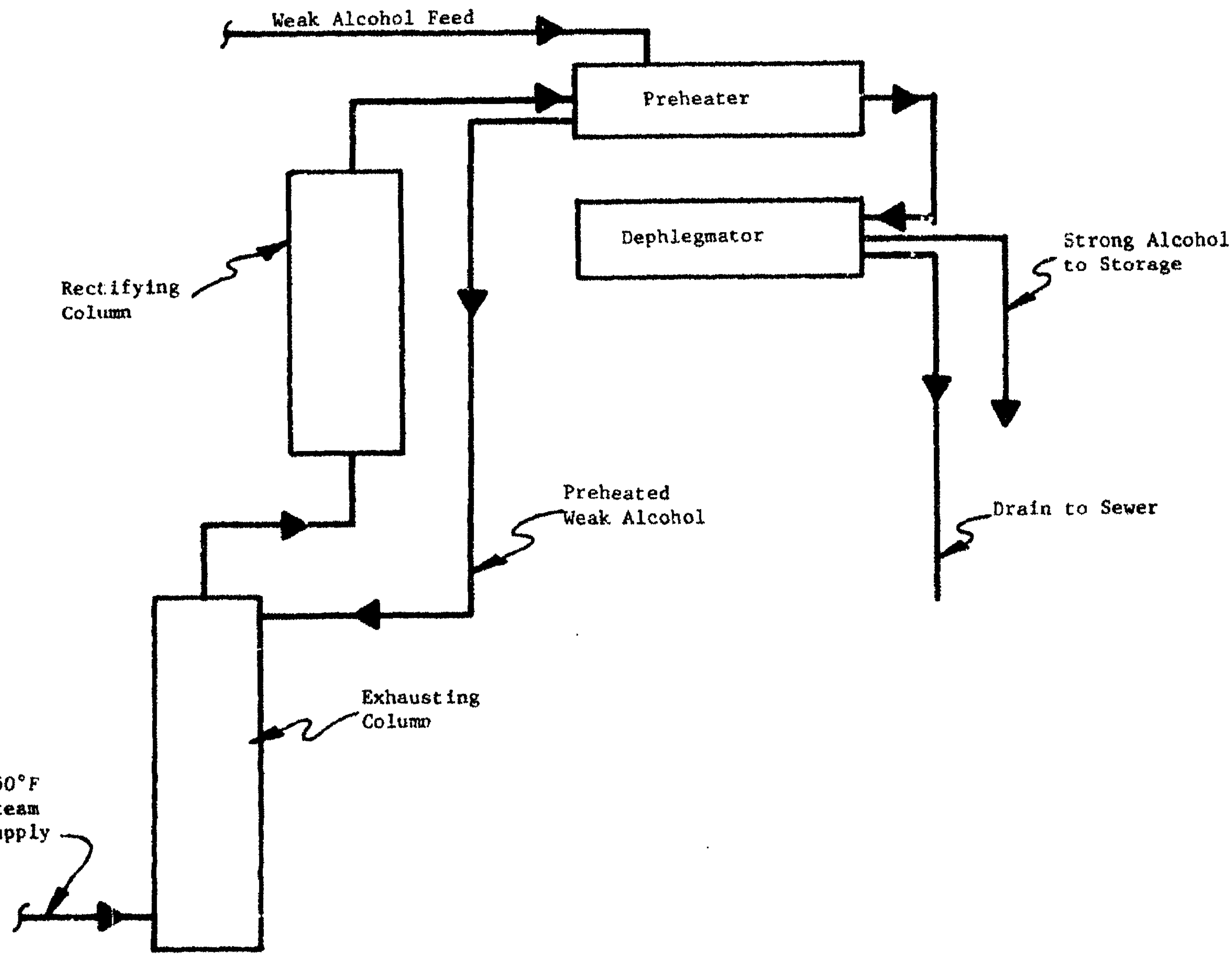

Figure 23. Schematic of alcohol rectification

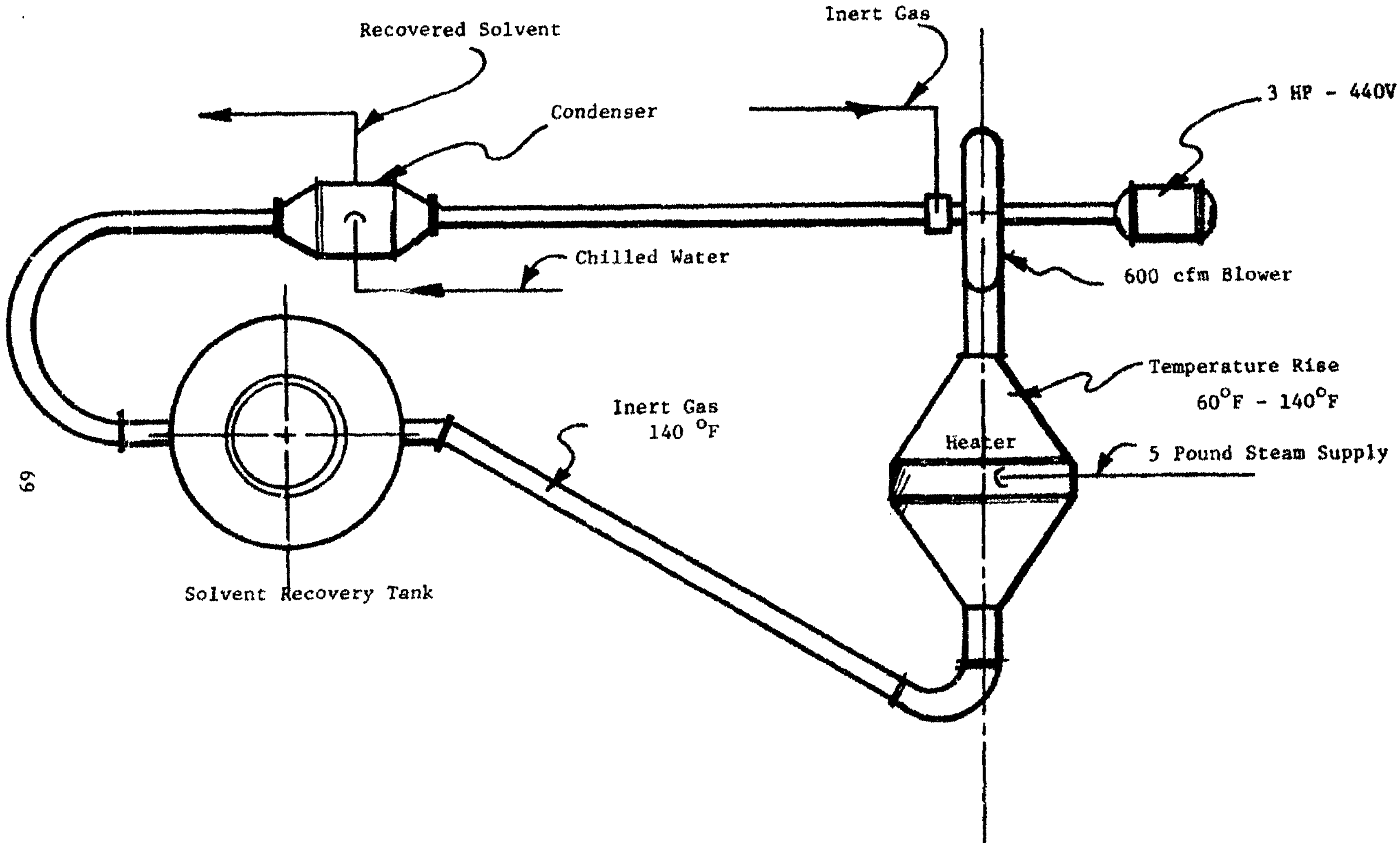

Figure 24. Schematic of solvent recovery

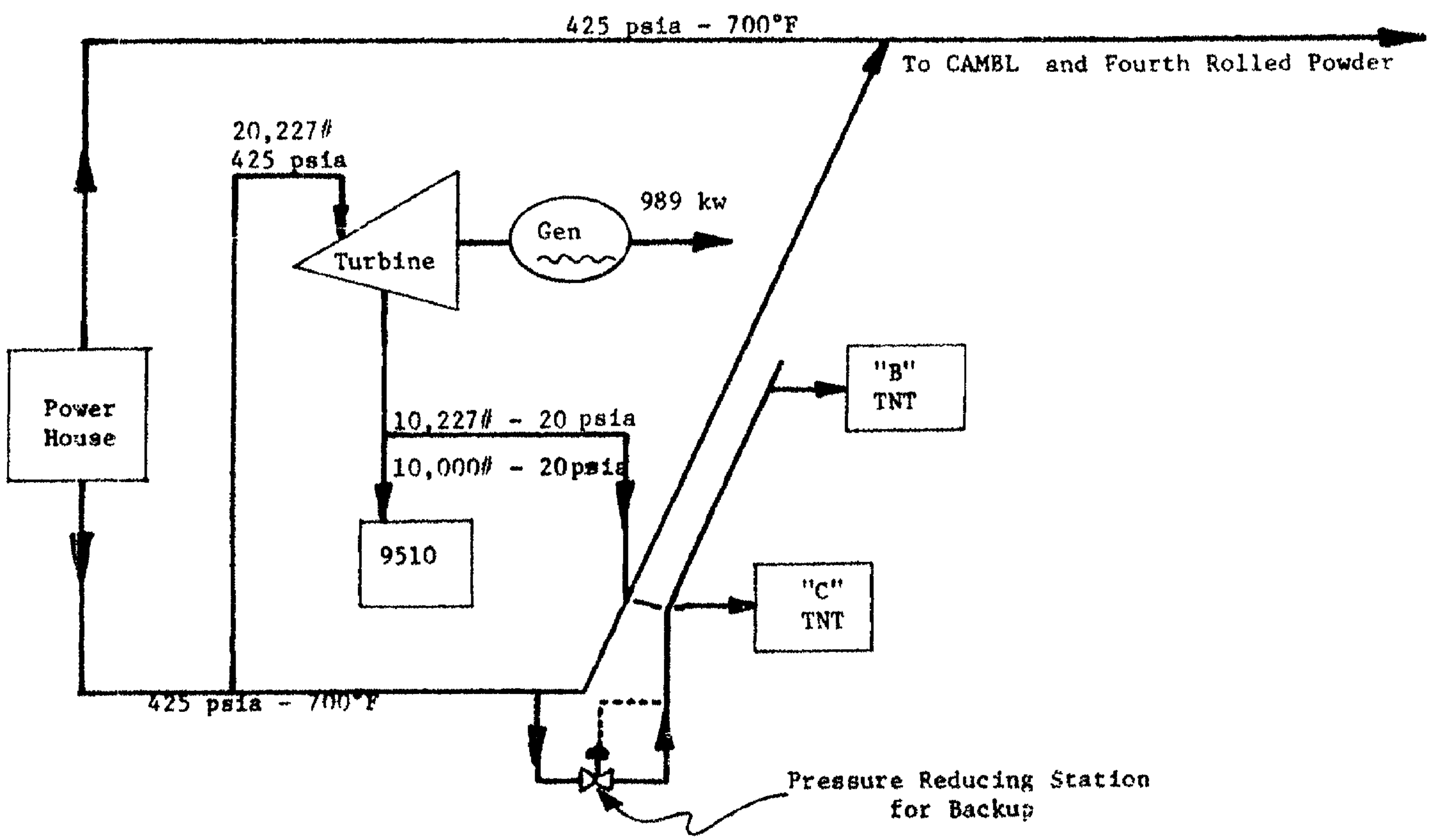

Figure 25. Schematic of topping turbine for TNT area

APPENDIX A

COMBUSTION EFFICIENCY, BOILER HOUSE No. 1

APPENDIX A

COMBUSTION EFFICIENCY, BOILER HOUSE No. 1

1 lb coal with 7.5 evaporation ratio makes 7.5 cu ft steam

24 cu ft steam = 1 kw

$$\frac{24 \text{ cu ft steam/kw}}{7.5 \text{ cu ft/lb}} = 3.2 \text{ lbs coal/kw}$$

3.2 lbs coal/kw x 13,500 Btu/lb coal = 43,200 Btu/kw

$$\% \text{ efficiency} = \frac{\text{Evaporation ratio x heat content of steam}}{\text{Calorific value of fuel}} \times 100$$

$$\% \text{ efficiency} = \frac{7.5 \times 1175.6 \text{ Btu/lb}}{13,500 \text{ Btu/lb}} \times 100 = 65\%$$

APPENDIX B

RAAP'S SURVEY EQUIPMENT

APPENDIX B

RAAP'S SURVEY EQUIPMENT

The following equipment was used to monitor energy consumption in this project:

Steam

Annubars	4 inches to 12 inches (Dietrick Standard Corporation
Orifice plates	2 inches to 3 inches (Foxboro)
d/p cells	Foxboro and Taylor
Chart recorders	Foxboro and Taylor
Controllers	Foxboro Model 43AP
Low signal selector	Moore Products Company
Pneumatic signal transmitters	Foxboro Model M-12A
Mercoid switch	Foxboro Model DAE-31-2
Low signal limiter	Foxboro Model B114-YB

Electricity

KWH meter - 440V

kw meter - 2300 V

Timer (for Jordan beaters)

Amp meters

Current transformers

APPENDIX C

TYPICAL SAVINGS THROUGH MOTOR POWER FACTOR CORRECTIONS

APPENDIX C

TYPICAL SAVINGS THROUGH MOTOR POWER FACTOR CORRECTIONS

Assumptions:

(1) Power factor correction is from 0.85 to 0.95
(2) Typical motor requires 32 kw for operation

Kva demands for power factors of 0.85 and 0.95 are:

$$Kva_1 = \frac{kw}{pf} = \frac{30}{0.85} = 37.64$$

$$Kva_2 = \frac{32}{0.95} = 33.68$$

Kva reduction for motor = 37.64 - 33.68 = 3.96 Kva

To make a complete evaluation of energy saved by power factor correction, the following assumptions are made:

(1) A total of 1000 motors will operate an average of 50% of the time at MOB.

(2) Power factor reductions will result in an energy saving of 3.71 Kva per motor.

$$Kw = Kva \times PF = 3.96 \times 0.95 = 3.76 \text{ kw}$$

$$3.76 \ \frac{kw}{motor} \times 1000 \text{ motors} \times 4380 \text{ hrs/yr} = 16,477,560 \text{ KWH/yr}$$

$$16,477,560 \text{ KWH/yr} \times 3415 \text{ Btu/KWH} = 56,271. \ 10^6 \text{ Btu/yr}$$

APPENDIX D

CALCULATIONS OF STEAM USAGE FOR A NITROCELLULOSE BOILING OPERATION CYCLE

APPENDIX D

CALCULATIONS OF STEAM USAGE FOR A NITROCELLULOSE BOILING OPERATION CYCLE

Basis for Calculations:

1. Lbs water in boiling tub when processing pulp:
   $\pi \times 9^2 \times 11$ = 2,799 cu ft
   $\underline{-\ 288}$ cu ft of NC 30,000 lbs
   = 2,511 cu ft x 62.4 lb/cu ft = 156,686 lbs

2. Lbs water in boiling tub when processing linters:
   $11' \times \pi \times 9^2$ = 2,799 cu ft
   $\underline{-\ 221}$ cu ft of NC 23,000 lbs
   = 2,578 cu ft x 62.4 lb/cu ft = 160,867 lbs

3. Wash water (filtered) temperatures: min 35°F; max 77°F; avg 56°F

4. NC slurry temperature: Min 70°F; max 75°F; avg 72.5°F

5. Weight of pulp/tub: 30,000 lbs

6. Weight of linters/tub: 23,000 lbs

7. Weight of boiling tub: 11,600 lbs (3/16" SS tub)

8. Specific heat of boiling tub: 0.11 Btu/lb/°F

9. Specific heat of NC: 0.35 Btu/lb/°F

10. Temperature of boiling tub @ boil: 205°F

11. U for vertical surfaces of boiling tub: 1.7

12. U for horizontal surface of boiling tub: 1.4

13. Enthalpy at 40 psig saturated steam: 1175.6 Btu/lb

14. Σ heat requirements = Btu required to bring tank, water and NC up to boil and Btu heat loss through walls of tank

15. Volume of NC in tub $= \dfrac{23,000}{62.4 \times 1.67}$ = 221 cu ft (cotton linters)
    $\dfrac{30,000}{62.4 \times 1.67}$ = 288 cu ft (woodpulp)

16. The average boiling time for processing P-1 (40 hrs) and P-7 (20 hrs) pulp consists of a 30-hour acid boil and two 5-hour neutral boils.

17. The average boiling time for processing BL-1 (40 hrs) and BL-7 (50 hrs) cotton linters consists of a 45-hour acid boil and two 5-hour neutral boils.

Heat required for one boiling tub cycle in Btu for processing wood-pulp NC.

Step 1

Heat Required to Bring Slurry up to Boil - Btu's

Water lb (156,686)	x t (203-72.5)	x Sp Ht (1.0)	=	20,760,895	
Tank lb (11,600)	x t (132.5)	x Sp Ht (0.11)	=	169,070	
NC lb (30,000)	x t (132.5)	x Sp Ht (0.35)	=	1,391,250	
		Subtotal			22,321,215

Step 2

Heat Loss during 6 Hr Period - Bring Tub up to Boil

(Temp. rise 72.5 to 205 = 132.5. Use average $t = \frac{132.5}{2} = 66$)

Q = U x Area x t x Time

Side:

$Q = 1.7\ (\pi \times 18 \times 12) \times 66 \times 6 \quad = \quad 456,824$

Top:

$Q = 1.4\ (\pi \times 9^2) \times 66 \times 6 \quad = \quad 141,078$

Subtotal 597,902

Step 3

Heat Required to Bring NC up to Boil after Water Wash (2 Times)

Water lb (156,686)	x Δt (205056)	x Sp Ht (1.0)	=	23,346,214	
Tank lb (11,600)	x Δt (149)	x Sp Ht (0.11)	=	190,124	
NC lb (30,000)	x Δt (149)	x Sp Ht (0.35)	=	1,564,500	
		Subtotal x 2			50,201,676

Step 4

Heat Loss during Two 4.5 Hr (= 9 Hr) to Bring Tub up to Boil

(Temp. rise 56°F to 205°F = Δt 149°F, Use avg. $\Delta t = \frac{149}{2} = 74$)

Side:

$Q = 1.7\ (\pi \times 18 \times 12) \times 74 \times 9 \quad = \quad 768,294$

Top:

$Q = 1.4\ (\pi \times 9^2) \times 74 \times 9 \quad = \quad 237,267$

Subtotal 1,005,561

Step 5

Heat Loss during Boil Time: 30 + 5 + 5 = 40 Total Hours
and Δt = boil temperature 205 - 85 ambient temperature = 120°F

Side:
$Q - 1.7 (\pi \times 18 \times 12) \times 120 \times 40$ = 5,537,245
Top:
$Q = 1.4 (\pi \times 9^2) \times 120 \times 40$ = 1,710,032

Subtotal 7,247,277

Total Btu Cycle Requirement for Processing Woodpulp NC:

Step	Btu Requirement
1	22,231,215
2	597,902
3	50,201,676
4	1,005,561
5	7,247,277
Total	81,373,631

Equivalent Steam Requirement (Max. Cycle Time) $= \frac{81,373,631 \text{ Btu cycle}}{1175.6 \text{ Btu/lb steam}}$

= 69,219 lb steam/cycle

Heat required for one boiling tub cycle in Btu for processing cotton linters NC:

Step 1

Heat Required to Bring Slurry up to Boil - Btu's

Water lb (160,867) x Δt (205-72.5) x Sp Ht (1.0) = 21,314,877
Tank lb (11,600) x Δt (132.5) x Sp Ht (0.11) = 169,070
NC lb (23,000) x Δt (132.5) x Sp Ht (0.35) = 1,066,625

Subtotal 22,550,572

Step 2

Heat Loss during 6 Hr Period - Bring Tub up to Boil
(Temp. rise 72.5 to 205 = t 132.5 Use average $\Delta t = \frac{132.5}{2} = 66$)

$Q - U \times \text{Area} \times \Delta t \times \text{Time}$
Side:
$Q = 1.7 (\pi \times 18 \times 12) \times 66 \times 6$ = 456,824
Top:
$Q = 1.4 (\pi \times 9^2) \times 66 \times 6$ = 141,078

Subtotal 597,902

Step 3

Heat Required to Bring NC up to Boil after Water Wash (2 Times)

Water lb (160,867)	x Δt (205-56)	x Sp Ht (1.0)	=	23,969,183
Tank lb (11,600)	x Δt (149)	x Sp Ht (0.11)	=	190,124
NC lb (23,000)	x Δt (149)	x Sp Ht (0.35)	=	1,199,450

Subtotal 25,358,757

Subtotal x 2 50,717,514

Step 4

Heat Loss during Two 4.5 Hr (= 9 Hr) Periods - Bring Tub up to Boil (Temp.) rise 56°F to 205°F - Δt 149°F. Use avg $\Delta t = \frac{149}{2} = 74°$ t)

Side:

$Q = 1.7\ (\pi \times 18 \times 12) \times 74 \times 9$ = 768,294

Top:

$Q = 1.4\ (\pi \times 9^2) \times 120 \times 55$ = 237,267

Subtotal 1,005,561

Step 5

Heat Loss during Boiling Time 45 + 5 = 5 = Total Hrs 55 and t - Boil temp. 205 - ambient temp. 85 - 120°F

Side:

Q = 1.7 (x 18 x 12) x 120 x 55) = 7,613,712

Top:

Q = 1.4 (x 9^2) x 120 x 55 = 2,351,294

Subtotal 9,965,006

Total Btu Cycle Requirement for Processing Cotton Linters

Step	Btu Requirement
1	22,550,572
2	597,902
3	50,717,514
4	1,005,561
5	9,965,006
Total	84,836,555

Equivalent Steam Requirement (Min. Cycle Time = $\frac{84,836,555 \text{ Btu/cycle}}{1175.6 \text{ Btu/lb steam}}$

= 72,164 lb steam/cycle

APPENDIX E

ESTIMATED SAVINGS USING AUTOMATIC TEMPERATURE CONTROL ON BOILING TUBS

APPENDIX E

ESTIMATED SAVINGS USING AUTOMATIC TEMPERATURE CONTROL ON BOILING TUBS

I. Automatic Controls With Insulated Tub

Savings based on normal usage rate from 22 months of measurement, table 3, where steam usage averaged 9.26 kg steam/kg NC.
MOB rated based on $144 \times 10^6 \frac{\text{lbs NC}}{\text{Yr}} = 65.32 \times 10^6$ kg NC/yr

Steam usage = 65.32×10^6 kg NC/yr x 9.26 kg steam/kg NC = 604.84×10^6 kg steam/yr

Based on MOB rate of 144×10^6 lbs NC/yr - High grade production of 72.7%

Time on Boil for High grade approximately 63% of time
Time on Boil for Low grade approximately 50.1% of time

Steam usage for High grade = 604.84×10^6 kg steam/yr x 27.3% x 63%
277×10^6 kgs/yr

Steam usage On Boil - Low grade = 604.84×10^6 kg steam/yr x 27.3% x 50.1% =
$\underline{82.7 \times 10^6 \text{ kgs/yr}}$

Total Steam Usage for "On-Boil" Manual Control 359.7×10^6 kgs/yr
Uninsulated Tubs

Steam Usage with Automated Controls and Insulated Tub
Rate table 5 = 309 kg steam/hr when On Boil
Average time on boil calculated for MOB rate = 44.54 hrs/cycle
309 kg steam/hr x 44.54 hrs/cycle x 4920 cycles/yr = 67.713×10^6 kgs/yr

Steam savings = $359.7 \times 10^6 - 67.713 \times 10^6$ kgs/yr = 291.987×10^6 kgs/yr

II. Savings Using Insulated Tub

Steam usage in single tub before insulation - Manual control "On-Boil" table 4 - Average	=	857 kg/hr
Steam usage - insulated tub on boil-manual control - table 5	=	<u>701</u> kg/hr
Steam Savings Using Insulated Tubs	=	156 kg/hr

APPENDIX F

CALCULATION OF STEAM USAGE FOR A NITROCELLULOSE POACHER OPERATION (STAINLESS AND WOODEN TUB)

APPENDIX F

CALCULATION OF STEAM USAGE FOR A NITROCELLULOSE POACHER OPERATION (STAINLESS AND WOODEN TUB)

Basis for Calculations:

1. Lb water in a poacher tub when processing either linters or pulp:

$$\pi \times 9^2 \times 8 = 2{,}036 \text{ cu ft}$$

Less volume of NC = $\underline{110}$ cu ft

1,926 cu ft x 62.4 = 120,182 lb

2. Wash water (filtered) temp.: Min 35°F; Max 77°F; Avg 56°F
3. NC slurry temp : 70°F
4. Wt. of NC in tub: 11,500 lb
5. Wt. of poacher tub (SS): 11,600 lb
6. Weight of poacher tub (wood, 2-1/2 inches thick): 11,279 lb
7. Specific heat of SS tub: 0.11 Btu/lb/°F
8. Specific heat of wood tub: 0.467 Btu/lb/°F
9. Specific heat NC: 0.35 Btu/lb/°F
10. Temperature of poacher @ boil: 205°F
11. μ for vertical surface SS tub: 1.7

    μ for horizontal surface SS tub: 1.4
12. μ for vertical surface wood tub: 0.2351

    μ for horizontal surface wood tub: 0.201
13. Enthalpy 40 psig saturated steam: 1175.6 Btu/lb
14. Volume NC in tub $\frac{11{,}500}{62.4 \times 1.67} = 110$ cu ft
15. Σ heat requirement:
    1. Btu required to bring tank water and NC to boil and heat loss through tank.
    2. Btu to hold at boil and heat loss through tank.

Calculations for Stainless Steel Tub:

Step 1

Heat Required to Bring SS Poacher up to Soda Ash Boil - Btu

Water lb (120,182) x Δt (205-70) x Sp Ht (1.0)	=	16,224,570		
Tank lb (11,600) x Δt (135) x Sp Ht (0.11)	=	172,260		
NC lb (11,500) x Δt (135) x Sp Ht (0.35)	=	543,375		
			Subtotal	16,940,205

Step 2

Heat Loss Bring Poacher up to Soda Ash Boil SS

$\Delta t = \frac{135}{2} = 67°F$

Side:

$Q = \mu \times Area \times \Delta t \times Time$

$Q = 1.7 \times (\pi \times 18 \times 12) \times 67 \times 1.75$	=	135,259		
Top:				
$Q = 1.4\ (\pi \times 9^2) \times 67 \times 1.75$	=	41,771		
			Subtotal	177,030

Step 3

Heat Loss during Soda Boil and Three Neutral Boils

ΣTime 8 Hr; Ambient temperature in building = 85°F

$\Delta t = 205 - 85 = 120°F$

Side:

$Q = \mu \times Area \times \Delta t \times Time$

$Q = 1.7 \times \pi \times 18 \times 12 \times 120 \times 8$	=	1,107,451		
Top:				
$Q = 1.4 \times \pi \times 9^2 \times 120 \times 8$	=	342,007		
			Subtotal	1,449,458

Step 4

Heat Required to Bring Poacher up to Boil after Draining (3 Times)

$\Delta t = 205 - 164 = 41°F$

Water lb (120,182) x Δt (41) x Sp Ht (1.0)	=	4,927,462		
Tank lb (11,600) x Δt (41) x Sp Ht (0.11)	=	52,316		
NC lb (11,500) x Δt (41) x Sp Ht (0.35)	=	165,025		
			Subtotal	5,144,803
			Subtotal x 3	15,434,409

Step 5

Heat Loss while Bringing Poacher up to Neutral Boil (3 Times)

$\Delta t = \frac{205 - 164}{2} = 21°F$; Time = 0.5 hour

Side:

$Q = 1.7 \times \pi \times 18 \times 12 \times 21 \times 0.5$	=	12,113	
Top:			
$Q = 1.4 \times \pi \times 9^2 \times 21 \times 0.5$	=	3,741	
	Subtotal		15,854
	Subtotal x 3		47,562

Total Btu Cycle Requirements for Stainless Steel Poaching Tub:

Step	Btu Requirement
1	16,940,205
2	177,030
3	1,449,458
4	15,434,409
5	47,562
Total	34,048,664

Equivalent Steam Requirement for One Poaching Cycle (Stainless Tub):

$$= \frac{34{,}048{,}774 \text{ Btu/cycle}}{1{,}175.6 \text{ Btu/lb steam}}$$

$$= 28{,}963 \text{ lb steam/cycle}$$

$$\frac{28{,}963 \text{ lb steam/cycle}}{11{,}500 \text{ lb NC}}$$

$$= \frac{2.518 \text{ lb steam}}{\text{lb NC}}$$

or 2.518 kg steam/kg NC

Calculations for Wooden Tub:

Step 1

Heat Required to Bring Poacher Tub up to Soda Ash Boil - Btu

$\Delta t = 135°F$

Water lb (120,182) x Δt (135) x Sp Ht (1.0)	=	16,224,570	
Tank lb (11,279) x Δt (135) x Sp Ht (0.467)	=	711,085	
NC lb (11,500) x Δt (135) x Sp Ht (0.35)	=	543,375	
	Subtotal		17,479,030

Step 2

Heat Loss to Bring Poacher up to Soda Ash Boil

$\Delta t = 67°F$

Side:			
$Q = 0.2351 \times \pi \times 18 \times 12 \times 67 \times 1.75$	=	18,705	
Top:			
$Q = 0.201 \times \pi \times 9^2 \times 67 \times 1.75$	=	5,997	
	Subtotal		24,702

Step 3

Heat Loss during Soda and 3 Neutral Boils (8 hr)

$\Delta t = 120°F$

Side:			
$Q = 0.2351 \times \pi \times 18 \times 12 \times 120 \times 8$	=	153,154	
Top:			
$Q = 0.201 \times \pi \times 9^2 \times 120 \times 8$	=	49,102	
	Subtotal		202,256

Step 4

Heat Required to Bring up to Boil after Draining and Refilling 3 Times

$\Delta t = 205 - 165 = 40°F$

Water lb (120,182) x Δt (40) x Sp Ht (1.0)	=	4,807,280	
Tank lb (11,279) x Δt (40) x Sp Ht (0.467)	=	219,098	
NC lb (11,500) x Δt (40) x Sp Ht (0.35)	=	161,000	
	Subtotal		5,187,378
	Subtotal x 3		15,562,134

Step 5

Heat Loss while Bringing Poacher up to Boil 3 Times

$\Delta t = \frac{205 - 165}{2} = 20°F$; Time = 0.5 hour

Side:			
$Q = 0.02351 \times \pi \times 18 \times 12 \times 20 \times 0.5$	=	1,595	
Top:			
$Q = 0.201 \times \pi \times 9^2 \times 20 \times 0.5$	=	511	
	Subtotal		2,106
	Subtotal x 3		6,318

Total Btu Cycle Requirement for Wooden Poaching Tub:

Step	Btu Requirement
1	17,479,030
2	24,702
3	202,256
4	15,562,134
5	6,318
Total	33,302,810

Equivalent Steam Requirement for One Poaching Cycle (Wooden Tub):

$$= \frac{33,302,810 \text{ Btu/cycle}}{1,175.6 \text{ Btu/lb steam}}$$

$$= 28,328 \text{ lb steam/cycle}$$

$$\frac{28,328 \text{ lb steam}}{11,500 \text{ lb NC}}$$

$$= 2.463 \text{ lb steam/lb NC}$$

or 2.463 kg steam/kg NC

APPENDIX G

ECONOMIC ANALYSIS FOR POACHER OPERATION HEAT RECOVERY

APPENDIX G

ECONOMIC ANALYSIS FOR POACHER OPERATION HEAT RECOVERY

Efficiency (n) is a measure of the fraction of heat recovered as a function of time:

$$n = \frac{(1 - e^{-NTU})}{tc} (1 - e^{-t^c})$$

where NTU is the number of transfer units and t^c is the system time constant

$$NTU = \frac{UPL}{C}$$

where U is the overall heat transfer coefficient, PL is the heat transfer area upon which U is based, and C is $(MC_p)_H$

where M_H is mass flow rate of the waste stream and $C_{p,}H$ is its specific heat

$$t^c = \frac{(1 - e^{-NTU}) \ Ct}{C}$$

where t is time
and C = p Cp V
where p is density of reservoir fluid
Cp is its specific heat
and V is the reservoir volume

The unit has been sized to provide one NTU with a flow rate of 113,000 lb/hr. For a storage quantity of 160,000 pounds and an emptying time of 84 minutes, the recovery efficiency is:

$$t^c = \frac{(1 - e^{-1}) \ 113{,}000 \ (1.4)}{160{,}000}$$

$$t^c = 0.625$$

and

$$n = \frac{(1 - e^{-1})}{0.625} (1 - e^{-0.625})$$

$$n = 0.47$$

A. Energy Comparison

1. Present Operation

Steam is used in the poacher house to bring the water-NC mixture to a boil (four times per cycle) and maintain boiling for a total of approximately 8 hours. Steam requirements are set by the volume and temperature of the water, NC and tank mass as well as heat loss during the heating and boiling. The use of the proposed recovery system will not change heat losses during the boils. Losses during the heating period will be reduced since the heating time is less; but these savings are small compared to the savings in bringing the tank to a boil. The tank temperature for one cycle is shown below. The temperatures shown are based on yearly average water temperature of the RAAP poaching operation.

The following conditions were assumed as the basis for calculation:

Water in poacher tub:

$$Wt = p\ (V_{water} - V_{NC})$$

$$= 62.4\ [\Pi(9)^2 \times 8 - 115] = 119{,}855 \text{ lb}$$

Washwater temperature:

Min: 35°F; Max: 77°F Avg: 56°F

Temperature of poacher at boil = 205°F

NC slurry temperature = 70°F

Weight of NC in tubs = 11,500 lb

Weight of S.S. poacher tub = 11,600 lb

C_p(NC) = 0.35 Btu/lb °F

C_p(S.S) = 0.11 Btu/lb °F

$C_p(H_2O)$ = 1.0 Btu/lb °F

Eight feet of water in tub at each boil

The energy required to bring the poacher tub to a boil = 16,940,205 Btu (see appendix F).

The following nitrocellulose poaching boil and wash sequence and quantities of both water and steam reflect the current techniques and procedures being used in the poaching operation.

a. The poacher tub containing the 11,500 pound batch of NC is filled with filtered water at 56°F to the eight foot level, soda ash is added and steam is applied to raise the tub and contents to 205°F. This temperature is maintained for a four hour boil.

b. Three feet of 56°F water is added to the eight feet in the tub and the mixture is agitated for 15 minutes without additional heat. After the NC settles, three feet of water are decanted.

c. The remaining eight feet of slurry are raised to a temperature of 205°F for the second boil of two hours.

d. There are two additional washes of three foot water adds at 56°F alternating with two additional one hour boils of eight feet of residual water at 205°F. The fourth boil ends the poaching treatment and the eight feet of 205°F water are drained.

The total heat requirement for the four boils to complete one poaching cycle is:

First boil - Qt = 16,940,205 Btu

Remaining boils - 8 ft H_2O @ 205°F and 3 ft H_2O @ 56°F

$$[(8 \times 205) + (3 \times 56)] \div 11$$
$$= 11 \text{ ft } H_2O \text{ @ } 164°F \text{ (wash water)}$$

Heat 9 ft H_2O from 164°F to 205°F

Filtered H_2O - 62.4 [(3.1416 x 81 x 9) - 115] (205 - 164)(1.0)	=	5,565,099 Btu
Tank - (11,600) (205 - 164)(.11)	=	52,316 Btu
NC - (11,500) (205 - 164)(.35)	=	165,025 Btu
Total	=	5,782,440 Btu

Total Heat required:

16,940,205 Btu
5,782,440 Btu
22,722,645 Btu

At full production rates, one heat recovery unit will process wastewater from 174 poacher tub cycles per month to process 2,000,000 pounds of NC (equal to one-half the capacity of one NC line).

$$Q_T = 22{,}722{,}645 \times 174 = 3.9537 \times 10^9 \text{ Btu/month/unit (or one-half a line)}$$

The total energy use for poacher tubs at the full production rate for three NC lines is:

$$Q_T = 39.537 \times 10^8 \text{ Btu} \times 6 \text{ units} = 23.722 \times 10^9 \text{ Btu/month}$$

or $$23.722 \times 10^9 \times 12 = 28.467 \times 10^{10} \text{ Btu/yr}$$

2. Operation with Recovery Unit

The poacher cycle with heat recovery will have two changes in operation: the incoming fresh water temperature is significantly higher and the time to boil is reduced by approximately one-half each time. The amount of energy recovered is the recovery efficiency, n. For the proposed system n = 0.47 and the energy use is:

$$Q_T = (1 - n)\ 39.537 \times 10^8 = 0.53 \times 39.537 \times 10^8 = 20.955 \times 10^8 \text{ Btu/unit/month}$$

3. Savings - 39.537×10^8 Btu - 20.955 Btu = 18.582×10^8 Btu/unit/month

For 3 lines @ 4,000,000 lb NC/month $18.582 \times 10^8 \times 3 \times 2 = 11.1492 \times 10^9$ Btu/month

11.1492×10^9 Btu/month x 12 months/yr = 13.379×10^{10} Btu/yr

APPENDIX H

ESTIMATED SAVINGS USING AUTOMATIC TEMPERATURE CONTROLS ON POACHING TUBS

APPENDIX H

ESTIMATED SAVINGS USING AUTOMATIC TEMPERATURE CONTROLS ON POACHING TUBS

Assumption:

Energy required to maintain poacher tub "on-boil" with automatic temperature control is equal to that required for boiling tubs corrected for differences in water and NC masses.

Step 1:

Energy required to bring boiling tub to "on-boil" temp = 22,321,215 Btu

Energy required to bring poacher tub to "on-boil" temp = 16,940,205 Btu

$$\text{Correction due to less water and NC masses} = \frac{16,941,205}{27,321,215} = 0.7589$$

Step 2: (ref tables 4 and 5)

Steam required to maintain poacher tub "on-boil" temperature with manual control = 1901 x 0.7589 = 517 lbs/hr

Step 3:

Steam savings = 1443 lbs/hr - 517 lbs/hr = 926 lbs/hr

At MOB:

$$926 \text{ lbs/hr} \times 8 \text{ hrs/cycle} \times \frac{144,000,000 \frac{\text{lbs}}{\text{yr}}}{11,500 \frac{\text{lbs}}{\text{cycle}}} = 92,761,044 \frac{\text{lbs steam}}{\text{yr}}$$

$$92,761,044 \frac{\text{lbs steam}}{\text{yr}} \times 1175.6 \frac{\text{Btu}}{\text{lb}} = 109,050 \times 10^{6} \text{ Btu/yr}$$

APPENDIX I

CALCULATIONS OF STEAM USAGE FOR AN OPEN TANK AIR DRY FOR M1 PROPELLANT

APPENDIX I

CALCULATIONS OF STEAM USAGE FOR AN OPEN TANK AIR DRY FOR M1 PROPELLANT

Basis for Calculations:

1. Air flow through tank: 1.416 m^3/s (3,000 ft^3/min)
2. Temperature of air entering drying tank: 63°C (145°F)
3. Average ambient air temperature: 12°C (53°F)
4. Quantity of propellant being dried per tank: 2,494 kg (5,500 lb)
5. Specific heat of air: 0.237 cal/g C° (0.237 Btu/lb F°)
6. Density of air: 1.201 kg/m^3 (0.075 lb/ft^3)
7. Cycle time: 28,800 s (8 hrs)
8. Enthalpy of 40 psig saturated steam: 6.532×10^5 cal/kg (1175.6 Btu/lb)

Heat Loss for One Cycle per Kilogram of Propellant:

$$1.416\ m^3/s \times (63 - 12)\ C° \times 0.237\ cal/g\ C° \times 1.201\ kg/m^3 \times 2.88 \times 10^4\ s \times 1 \times 10^3\ g/kg = 5.920 \times 10^8\ cal$$

The equivalent requirement for one air dry cycle = 906 kg (1993 lb) of steam. The quantity of steam required to remove the moisture from one unit of propellant is as follows:

> 0.363 kg of steam per one kg of propellant (0.363 lb steam per one lb of propellant)

APPENDIX J

CALCULATION OF STEAM USAGE FOR A FORCED AIR DRY CYCLE FOR M30 PROPELLANT

APPENDIX J

CALCULATION OF STEAM USAGE FOR A FORCED AIR DRY CYCLE FOR M30 PROPELLANT

Basis for Calculations:

1. Air flow through drying bay: 1.698 m^3/s (3598 ft^3/min)
2. Temperature of air entering drying bay: 60°C (140°F)
3. Average ambient air temperature: 12°C (53°F)
4. Quantity of propellant being dried per bay: 5,670 kg (12,500 lb)
5. Specific heat of air: 0.237 cal/g C° (0.237 Btu/lb F°)
6. Density of air: 1.201 kg/m^3 (0.075 lb/ft^3)
7. Cycle time: 208,800 s (58 hrs)
8. Enthalpy at 40 psig saturated steam: 6.532×10^5 cal/kg (1175.6 Btu/lb)

Heat Required for One FAD Cycle per Kilogram of Propellant:

$$1.698\ m^3/s \times (60 - 12)\ C° \times 0.237\ cal/g\ C° \times 1.201\ kg/m^3 \times 2.088 \times 10^5\ s \times 1 \times 10^3\ g/kg = 4.844 \times 10^9\ cal$$

The equivalent requirement for one FAD cycle is 7,416 kg (16,315 lb) of steam. The quantity of steam required to remove solvents from one unit of propellant is as follows:

1.31 kg of steam per kg propellant (1.31 lb of steam per lb of propellant)

APPENDIX K

USE OF A "TOPPING" TURBINE TO PROVIDE STEAM AT REDUCED PRESSURE IN THE TNT AREA

APPENDIX K

USE OF A "TOPPING" TURBINE TO PROVIDE STEAM AT REDUCED PRESSURE IN THE TNT AREA

Basis for Calculations:

Steam demand: 10,000 lbs/hr to TNT Buildings
10,000 lbs/hr to CASBL

This 85,000 lbs/hr flow is equivalent to 10.2×10^7 Btu/hr.

Assume turbine is 75% efficient; generator is 95% efficient.

Steam supply = 425 psia; 700°F; 1362 h.

Steam discharge from turbine = 20 psig (for distribution to the users)

Specific Steam Consumption for Turbine (S_c):

$S_c = 3{,}412\ (E_g \times E_t \times h_a)$/KWH

E_g = generator efficiency

E_t = turbine efficiency

h_a = adiabatic heat drop

From Mollier diagram $h_a = 1362 - 1128 = 234$ Btu/lb and $0.75 \times 234 =$ 175.5 Btu/lb = actual drop through turbine.

$1362 - 175.5 = 1186.5$h = actual enthalpy of steam from turbine (20 psig); 295°F; 35°F superheat.

$S_c = 3412/(.95 \times .75 \times 234) = 20.46$ lbs steam per KWH

Steam Flow Required Through Turbine:

$10.2 \times 10^7/1186.5 = 85{,}967$ lbs/hr

Electricity Generated:

$85{,}967/20.46 = 4202$ kw

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