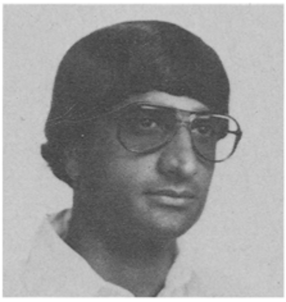

Energy Conservation in Solvent Extraction

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ABSTRACT

Increased costs for energy and unpredictable supplies of fuel have created a new dimension in business management. Energy and solvent costs account for 40-50% of total costs in operating an oilseed solvent extraction plant in the USA. Many companies are finding that an organized energy conservation program can hold down both energy use and costs without disrupting plant production. It has been repeatedly demonstrated that conservation measures can reduce energy by 15-30% or more with justifying cost savings. More importantly, if by energy conservation you can maintain production despite a reduction in energy supply, or increase production in the face of frozen fuel allocations, the effect on your sales and profits is obvious.

INTRODUCTION

The basic steps in managing an energy conservation program consist of: (a) making a corporate commitment to the program; (b) establishing well defined energy goals during basic design; (c) surveying energy uses and losses; (d) implementing energy conservation actions; and (e) continuing energy conservation efforts by obtaining the cooperation and support of the employees through the use of training programs, posters and periodic lectures.

Total consumption of energy in the USA is estimated at 88 quadrillion BTU per year, or 88 quads (1). This consumption represents 100% of US consumption. Total consumption for soybean plants of 0.075 quads/year is one-1100th of the total or less than a tenth of a percent of the total. Also, 2% of the total consumption is for the food sector or 23 times the consumption of all the soy processing plants. America's dishwashers use 0.9 times, televisions use 7 times and automobiles use 165 times as much energy as do all the soy processing plants.

American self-control has resurfaced on the energy front. The dire predictions in 1976 were that by the year 2000 the USA would consume 165 quads of energy. Well, Americans are now consuming even less than they were then, and the Commerce Department has cut its estimate for the year 2000 to 122 quads.

ENERGY USE IN SOLVENT EXTRACTION

Energy consumed in solvent extraction, producing high protein meals, is shown in Table I.

With these usages, if average costs for dryer fuel, boiler fuel and electricity are applied, following would be cost per unit. Hexane, at specific usage of 0.50 gal/ton is also added to reflect total energy costs (see Table II). Total energy and hexane cost of $8.50 would represent between 40 and 50% of the total manufacturing costs in operating a solvent extraction plant.

In looking at the energy breakdown, it is immediately apparent that the boiler is the greatest energy user and the most complex system with many kinds of inefficiencies. In fact, as indicated, one of the largest uses of energy in many plants is the inefficiency of the steam system—20% of the total use. The dryer, which also consumes 20% of the total energy, is a single plant use and can be understood independently; the electrical use is almost all in the form of motor horsepower which is fairly easy to sum up and to understand.

TABLE I

Energy Use

Use	BTU/ton	% of total
Dryer fuel	250,000	20[a]
Boiler fuel	850,000	68[b]
Electricity	150,000	12[c]
Total energy use	1,250,000	100

[a]Assumes soybean moisture removal of 2.5%.

[b]Assumes steam consumption of 680 lb/ton at 80% boiler efficiency.

[c]Assumes 43 kWh/ton for specific electrical consumption.

TABLE II

Energy Costs in Solvent Extraction

	$/ton	% of total energy	% of total energy and hexane
Dryer fuel[a]	1.25	16	15
Boiler fuel[a]	4.25	55	50
Electricity[b]	2.25	29	26
Total energy	7.75	100	91
Hexane[c]	0.75		9
Total energy and hexane	8.50		100

[a]Dryer and boiler fuel at $5.00/million BTU.

[b]Electricity at $15.00/million BTU.

[c]Hexane at $1.50/gal.

Let us first consider the dryer and see what can be done with it to make it operate efficiently.

DRYERS

In soybean processing in the USA, production of high protein meal is imperative, and hence the condition of the raw beans greatly affects what occurs during the process, and the end product. Thus, the more consistent the beans, the more predictable are process variables, allowing for optimization of variables. The best beans for processing, then, would be perfectly clean, like-sized beans of a constant, predetermined temperature and moisture content (2). To execute the above, dirty, wet beans received at the plants are cleaned and dried. The most common drying medium is air, and most dryers use it. The drying process described in Figure 1 consists of the following: (a) Sensible heating, where ambient air is heated with dryer fuel, whereby the specific humidity (lb of water/lb of dry air) remains constant, but the enthalpy is raised at saturation (BTU/lb of dry air); and (b) Adiabatic humidification, where the heated ripe air comes in contact with the incoming grain, dropping the dry-bulb temperature, increasing the specific humidity, but where the enthalpy remains constant.

Significant amounts of energy can be saved by recirculating the exhaust air. Figure 2 depicts a typical grain dryer air flow with 50% of the exhaust air recirculated. The system air volume is 200,000 CFM, with 50,000 CFM each of ambient air through the burners and cooling section and 100,000 CFM of the exhaust air being recirculated and introduced after the burners.

Table III illustrates the comparison of grain drying without and with recirculation and the savings in heat requirements. Note that 40% savings are realized in the example cited.

To maximize the capacity of grain dryer, process automation, in this case a programmable controller (PC) with corresponding sensing equipment (Fig. 3) is used. Besides measuring and recording various drying parameters, the

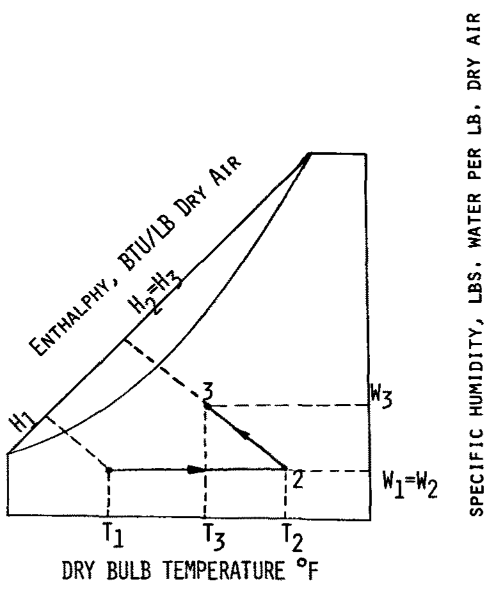

FIG. 1. Grain drying process–psychrometric chart. Process 1-2: sensible heating (no change in specific humidity). Process 2-3: adiabatic humidification (no change in enthalpy). Typical state points (Midwest USA, October through March): T_1 = 38 F, RH, = 50%; T_2 = 180 F; T_3 = 120 F.

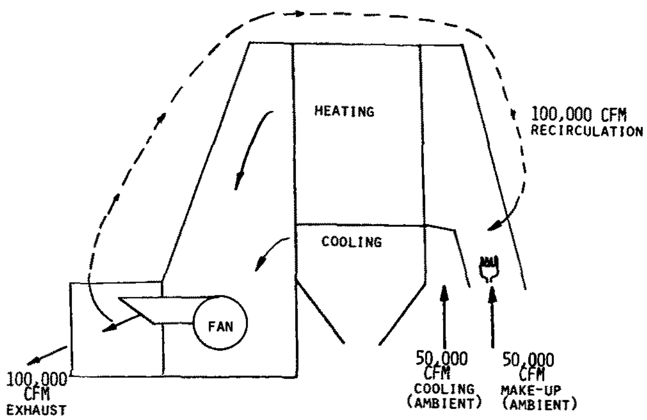

FIG. 2. Grain drying with recirculation of 50% of exhaust air. System volume = 200,000 CFM.

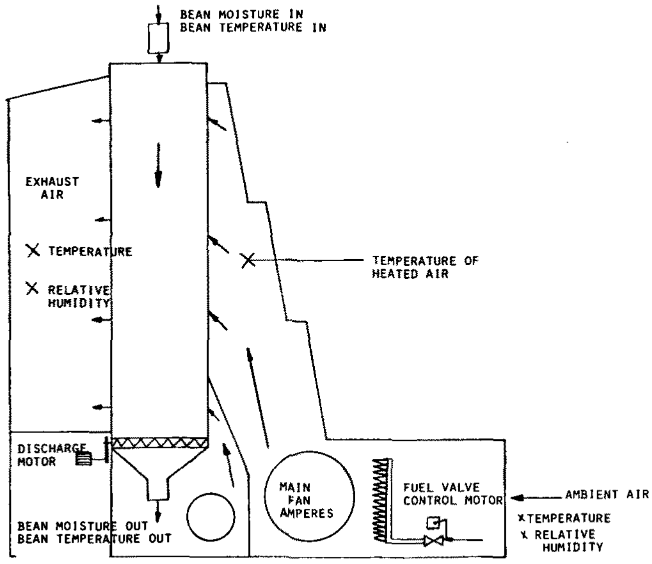

FIG. 3. Grain dryer automated control using Modicon 484 programmable controller, controlled and monitored parameters. The Modicon will control the fuel valve control motor and the speed of the product discharge motor.

TABLE III

Energy Savings with Recirculation

Item		Without recirculation	With recirculation
Cooling air flow	CFM	50,000	50,000
Ambient air to burners	CFM	150,000	50,000
Exhaust air to burners	CFM	0	100,000
Ambient temperature, Oct.-Mar.	F	38	38
Ambient RH, Oct.-Mar.	%	50	50
Heated air temperature	F	180	180
Heat air RH	%	3	4
Exhaust air temperature	F	120	120
Exhaust air RH	%	21	25
Heat requirement, Oct.-Mar.	10^6 BTU/hr	29.5	17.6
Savings in heat requirement	%	–	40

PC will control two dryer functions—the drying air temperature and the product discharge rate. The desired drying air temperature is maintained via the PC to move a control motor which is linked to the gas valve. The control of the dryer discharge rate will be controlled by sensing the wet bean moisture ahead of the dryer and the dry bean moisture on the dryer discharge. These signals are received by frequency controller that changes the speed of the motor driving the discharge rolls at the bottom of the column of beans.

Recent developments in producing high protein meals in solvent plants have been in drying oilseeds other than in column or tower dryers, e.g., in fluidized bed drying and microwave vacuum drying (Fig. 4). The MIVAC System (3), developed by McDonnell Aircraft Company, St. Louis, MO, is a breakthrough in drying technology. Its benefits are summarized for agricultural applications: (a) Quick—because the grain temperature is deliberately limited to a low value. (b) Quiet—there are no large air-volumes required to carry heat from the burner to the oilseeds. Operation is virtually silent. (c) Clean—there is no blowing air to suspend and carry dust and chaff. Local pollution problems are eliminated. (d) Efficient—pilot plant studies indicate the specific energy consumption for drying is substantially less than conventional drying. (e) Quality—better control over drying process by uniformity of drying on a particle-by-particle basis enables the processor to control heat to which the dried product must be raised. (f) Simplicity—the number of controls and moving parts is minimized. (g) Safety—the low temperature and vacuum environment during drying virtually eliminate the possibility of fires dreaded by all dryer operators. (h) Versatility—many different oilseeds can be accommodated with no change to the equipment.

As previously indicated, 12% of the energy consumed is electrical, which is in the form of motor horsepower (95%) and lighting (5%). Evaluating motors can be rather complicated, especially when it comes to energy efficiency. Perhaps the most confusing part of a motor evaluation is accounting for technical factors about the motor itself. Factors such as load conditions, expected life, horsepower requirements, etc., affect how much a motor will save (4). Pulling all these factors together can quickly become a real chore. The use of energy-efficient motors is probably one of the largest substantial savings for any given facility.

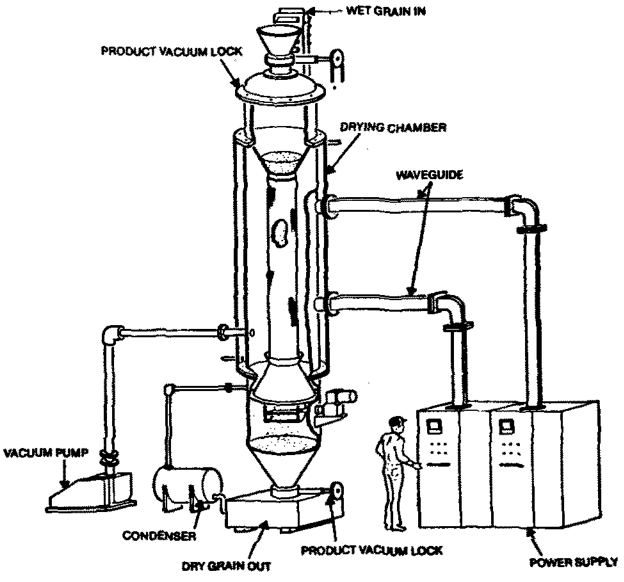

FIG. 4. Microwave vacuum drying.

A 100-HP motor, efficiency 93%, running continuously all year at 6¢/kWh, would cost ca. $42,000 to operate. Make the motor 95% efficient, and its operating cost will drop to $35,000. This saving calculated for a 1000 ton/day plant with total motor horsepower of 2500 HP would equal $175,000/year. Side benefits of using energy efficient motors are cooler running temperature, lower noise level, and improved power factor.

These benefits may be of great importance in solvent extraction plants where oilseed handling creates explosive conditions, meal and hull grinding generating high decibels, reducing penalties for low power factors, cost of installing capacitors and maximizing the capacity of the substation. A checklist for purchase of an energy-efficient motor is reflected in Table IV (5).

TABLE IV

Energy-Efficient Motors—Check List

1. Test according to the NEMA standards.
2. Thinner laminations—reduces eddy current.
3. Silicon steel.
4. The manufacturer should have tested a large population of motors in each rating to develop a data table that gives quality and consistency to each rating.
5. Manufacturers should have more standards for testing an energy-efficient motor than their standard motors.

Proper lighting in a solvent extraction plant is essential for efficient operations and security. For a 1000 ton/day plant, ca. 100,000 watts of lighting is needed, the annual cost being $26,400 for 4400 hr and 6¢/kWh. As with any energy-consuming device, simply turning lights off when not in use will reduce cost but, as with motors, efficient lighting can be justified quite easily.

Currently, three types of lighting are available: incandescent, fluorescent and high-intensity discharge (HID) lights. Incandescent lighting, the most popular, is very inefficient in electricity use. The lumens (the amount of brightness of light) to watts (amount of energy it takes to light the bulb) ratio ranges from 14 to 20. Fluorescent lights run cooler and are efficient, but the fixtures are prohibitive to be enclosed and maintained in a hazardous environment such as a solvent plant.

HID lights are classified into quartz, metal halide, low pressure sodium, mercury vapor and high-pressure sodium. The two most common types of lighting for hazardous locations are mercury vapor (MV) and high-pressure sodium (HPS). MV are not as energy efficient as HPS, but they emit white color so lighting appears to be natural. HPS lights have a lumens to watt ratio of between 50 and 70. In addition, they are cooler, and because they do not radiate as much heat, they are suitable for operation in hazardous/explosive environments.

Let us now consider the boiler room, where earlier it was indicated that 68% of the total energy in a solvent plant is consumed. Efficient steam production in the boiler room with subsequent wise use of steam produced is the key to keeping boiler fuel usage and costs down.

First, let us concentrate on efficient steam production in the boiler room. Figure 5 shows a flow diagram of a multifuel powerhouse. Following is a brief amplification on items that would make the powerhouse produce steam efficiently and cheaply.

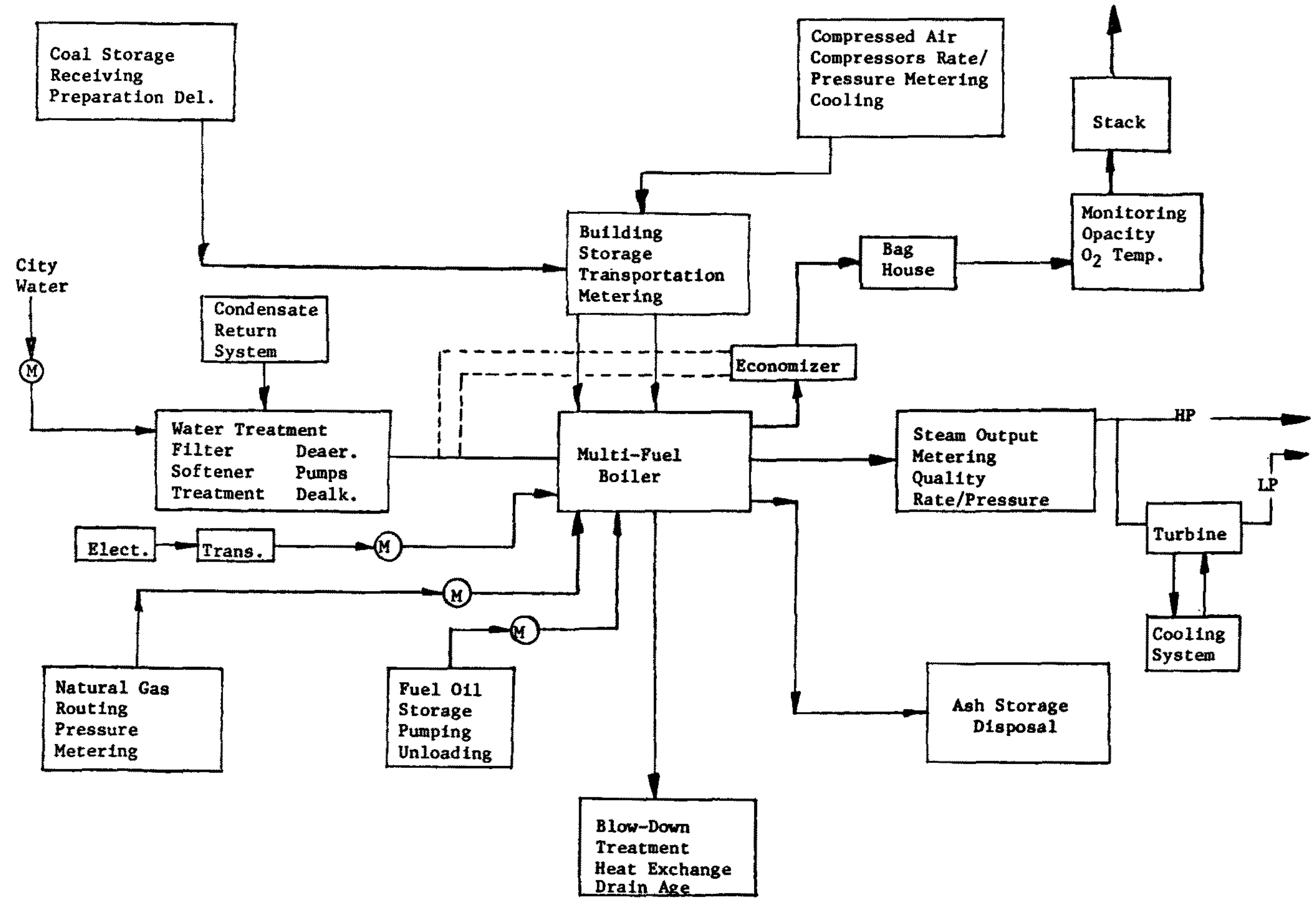

FIG. 5. Flow diagram of a multifuel powerhouse.

Multifuel boiler. This is a boiler that is versatile, so that it can either burn solid, liquid or gaseous fuel, whichever is cheapest and most abundant to fire. Figure 6 depicts a trifuel boiler made by CNB of Combustion Service and Equipment Company sold by ESI, Inc., of Tennessee. In addition to burning the cheapest fuel, the daily monitoring of boiler thermal efficiency is imperative because nearly 20% of the energy losses are encountered in producing steam from boiler fuels. Thermal efficiency of the boiler is defined as:

$$\frac{\text{Heat output}}{\text{Heat input}} = \frac{\begin{array}{c}(\text{steam produced, lb}) \times \\ (\text{heat absorbed in boiler, BTU/lb})\end{array}}{\begin{array}{c}(\text{boiler fuel, tons, gal, CF}) \times \\ (\text{heat value, BTU/ton, BTU/gal, BTU/CF})\end{array}}$$

As indicated in Figure 7, the higher the feedwater temperature, the less heat absorbed in the boiler to produce saturated steam at a given pressure and consequently the lower the boiler fuel consumption.

Boiler fuel metering. Measuring heat input into the boiler daily is essential in keeping track of boiler fuel consumption. There are meters to track gaseous fuels such as natural gas or propane, and Figure 6 shows the coal stoker which is calibrated to meter coal into the boiler.

Steam metering. Measuring heat output by recording steam consumption facilitates calculation of boiler thermal efficiencies.

Condensate handling system. Approximately 50% of the steam consumed in solvent extraction of oilseeds is sparge, the balance being jacket steam. Handling of condensate from all types of heating and processing equipment and returning to the boiler room is essential. The Johnson Liqui-Mover is one such system. Instead of pumps, the Liqui-Mover uses steam or other gases under pressure, as the motive force. Instead of balking at temperatures above

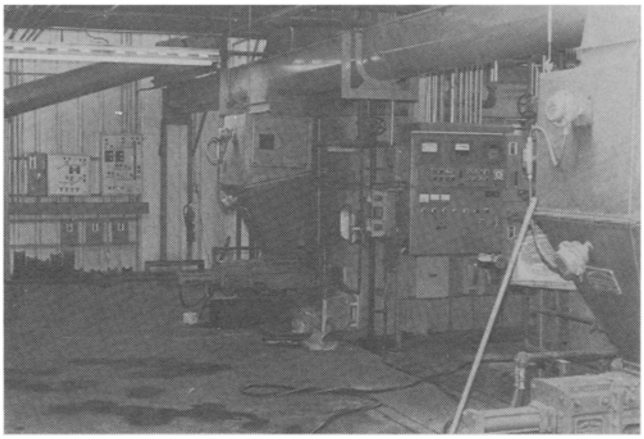

FIG. 6. A trifuel boiler made by CNB of Combustion Service and Equipment Company.

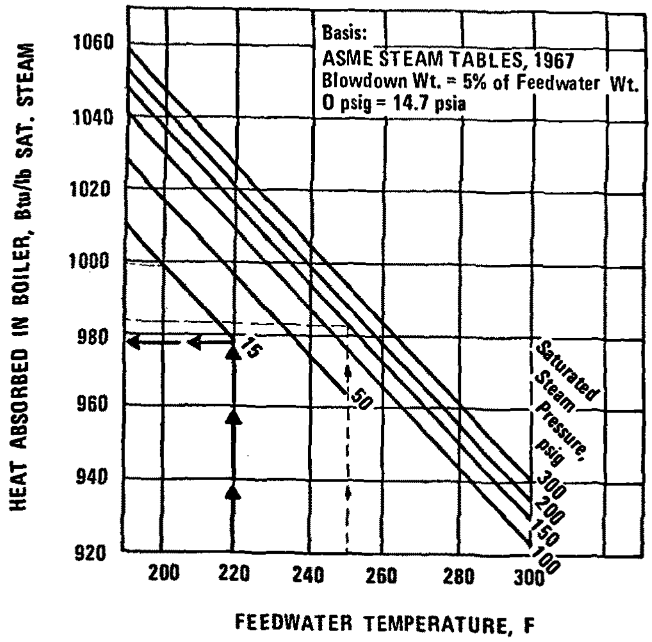

FIG. 7. Heat absorbed in generation of saturated steam.

185 F, it can handle condensate of any temperature without the need for venting or cooling. Instead of high-maintenance stuffing boxes, motors and starters, it has no revolving shafts and only a few moving parts.

Economizer. As indicated earlier the heat absorbed in the boiler decreases with increasing feedwater temperature, hence the reduction in boiler fuel consumption. The economizer uses the heat of flue gas and heats the feedwater as high as 252 F. At this feedwater temperature, the corresponding heat absorbed in the boiler at 150 psig is 983 BTU/lb vs 1000 BTU/lb for a feedwater temperature of 200 F. Figure 8 shows one kind of economizer. One point of caution is against corrosion due to the sulphur in the boiler fuel. Minimum recommended feedwater temperatures, acid dew points (SO_3) and recommended flue gas exit temperatures are related to the percentage sulphur in fuel, e.g., with 1.5% sulphur in boiler fuel, corresponding temperatures are 232 F, 274 F and 342 F.

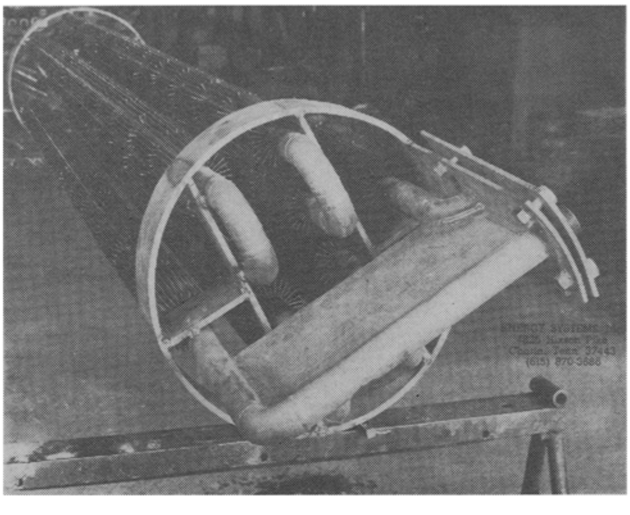

FIG. 8. Boiler economizer.

Blowdown heat exchangers. Between 3% and 5% of the total heat input into the boiler is given up in continuously blowing down a boiler or simply continuous blowdown. A good blowdown system removes the solids continuously and in proportion to how fast they are added in the makeup water. In addition, it recovers the heat from hot blowdown water and transfers it to the make-up water. As the blowdown and make-up flows occur simultaneously and in proportion, there is always make-up available to recover all of the blowdown heat. A properly sized blowdown system with good water treatment will assure one of clean and maximum boiler service life free from costly downtime due to breakdowns and excessive maintenance requirements.

Deaerators. The economics of deaeration as a way to beat the high costs for downtime or replacement of corroded boilers, boiler tubes, feedwater and condensate lines is unmistakable. The reason: any oxygen in the feedwater is corrosive. Failure to remove it to the lowest level possible is poor economics–a compromise one pays for with increasing need for chemicals and blowdowns that more than offset any initial savings.

Deaerators are capable of removing oxygen to 0.005 cc/L or less, and eliminate carbon dioxide. Most deaerators recover heat from exhaust and flash steam–otherwise a wasted asset–to raise and maintain boiler feedwater temperatures well beyond levels experienced with atmosphere deaerators. Normally, a deaerator will save 1% in fuel cost for every 10 F rise in feedwater temperature. Additional savings result from reduced need for chemical water treatment and extended periods between boiler blowdowns. Before concluding the efficient production of steam in the boiler room, a few maintenance procedures to save boiler fuel should be noted:

- Optimize combustion air requirements by adjusting dampers.
- Adjust burners for proper flame patterns.
- Arrange for periodic soot-blowing of convection tubes.
- Maintain only minimum boiler pressure required.
- Operate only a minimum number of boilers for safe and efficient operation.

Steam is used in the following unit operations:

- Desolventizing and toasting of meal.
- Drying and cooling of meal.
- Solvent recovery and heating.
- Bean conditioning.
- Hull toasting.
- Space-heating and line tracing.

Desolventizing and Toasting of Meal

Desolventizing and toasting (DT) solvent extracted meal accounts for the largest part of steam consumption, 35-45% of the total consumption. Factors affecting steam consumption are as follows.

Extraction. Shallow bed, ca. 24 in., drains almost completely in 30 sec, allowing thorough final drainage to ca. 28-31% solvent content in dehulled soybeans (1). This contrasts with deep bed units where the bed drains 120 in. in ca. 200 sec or longer–due to increased distance and higher bed pressures on lower flakes. Solvent in discharged meal commonly ranges from 33-36% in deep bed units. A difference of 5% at 1000 tons/day amounts to increased DT and meal dryer steam of 3962 pph or $160,000 per year (Table V).

Flake moisture. (Table VI [6]). One percent variation of flake moisture corresponds to 1.2% variation of the meal moisture while the quantity of steam increases slightly with the moisture.

Flake temperature. (Table VII [6]). A drop of 18 F in temperature of the spent flakes sent to the DT results in an increase of steam consumption of 833 pph, or $35,000/year for 1000 tons/day plant and steam costs of $5.00/1000 lb. Increase of meal moisture is also noted.

DT dome temperature. (Table VIII [3]). The DT dome temperature, for soybeans, is an indicator of the DT's efficiency. At 158 F, steam consumption for 1000 ton/day plant is 7167 pph, while at 176 F, the corresponding consumption is 9750 pph or increase of 2583 pph or $105,000 per year.

Heating surface (3). Increasing the heating surface increases the jacket (heating) steam and reduces the sparge (injected) and the result is a slight increase in total steam consumption in the DT, but with significant reduction in meal moistures at the outlet and thus reducing meal drying steam and overall steam consumed in the DT and drying.

Drying and Cooling of Meal

Steam consumed in meal drying accounts for 15-25% of the total steam consumption. The variation being because of the following factors:

- Type of dryer used (rotary steam tube, fluidbed dryer-cooler, or dryer-cooler section of the desolventizer/toaster/dryer/cooler (DTDC).
- Meal moisture exiting the DT (Table IX).
- Meal moisture exiting the dryer, or overdrying (see Table X).

The meal dryer and cooler should be with counter flow of air and a minimum of cool air so as to maximize the proportion of drying done by evaporative cooling. The result is that most of the meal and moisture heat are used efficiently to drive off moisture as the meal cools.

Solvent Recovery and Heating

Steam used in solvent recovery and heating is used for evaporation, miscella heating, hexane heating, stripping steam, waste water, steam ejectors, and mineral oil system.

Evaporation. Almost all evaporation in the 1st stage occurs with energy from the DT vapors. The main operational cost of the 1st stage evaporator is that of developing a vacuum on the tube side of the unit. Less vacuum, therefore less steam for the ejectors, is required if more tube area is used.

Table XI illustrates the extra energy consumed if the 1st-stage miscella evaporator does not do its full potential and the miscella to the second stage drops from 85% oil to 70% oil. At 1000 ton/day, the 2nd stage would require 871 pph more steam or $35,000/year.

TABLE V

Influence of Solvent Retention

Solvent carried to DT	30%	35%
DT steam condensed (pph)	5982	7118
DT dome at 165 F (pph)	3418	4263
DT tray steam (pph)	1096	1096
Meal dryer steam (pph)	4425	6406
Total DT and dryer	14921	18883

TABLE VI

Influence of Flake Moisture to DT

Flake moisture (%)	Injected steam[a] (pph)	Meal moisture (%)
9	8000	16.5
10	8167	17.7
11	8250	18.9
12	8333	20.1

[a] For 1000 tons/day plant.

TABLE VII

Influence of Flake Temperature to DT

Temperature (F)	Injected steam[a] (pph)	Meal moisture (%)
131	8250	18.9
122	8667	19.4
113	9083	19.9

[a] For 1000 tons/day plant.

TABLE VIII

Influence of DT Dome Temperature

Temperature (F)	Injected steam[a] (pph)	Meal moisture (%)
158	7167	18.9
167	8250	18.9
176	9750	18.8
185	13167	18.7

[a] For 1000 tons/day plant.

TABLE IX

Influence of Dryers and Moisture of Meal from DT on Meal Drying

	Moisture (%)	Steam[a] (pph)
Undersized conventional DT	21.0	10,416
Rotary steam dryer	13.5	6,667
Rotary air cooler	12.0	
Oversized conventional DT	19.0	10,833
Fluidbed dryer-cooler	12.0	3,333
DT section	19.0	10,167
DC section	12.0	4,167

[a] For 1000 tons/day plant.

TABLE X

Overdrying of Meal

Meal moisture (%)	12.0	11.5
DC dryer steam[a] (pph)	4167	5686

[a] For 1000 tons/day plant.

Savings of 1519 pph or $60,000/year at steam at $5.00/1000 lb.

TABLE XI

Steam Consumption vs Miscella Concentrations to 2nd-Stage Evaporator

2nd-Stage miscella (%)	70	85
2nd-Stage steam[a] (pph)	2373	1502

[a] For 1000 tons/day plant.

Miscella heating. Miscella leaving the 1st-stage evaporator is normally "cold"; the temperature averages 120 F and therefore needs to be heated before another stage of evaporation occurs. If "cold" miscella is pumped to the 2nd-stage evaporator, the tube area in it is used for heating instead of evaporating resulting in poor miscella concentrations exiting the 2nd-stage evaporator. Figure 9 shows a plate-type miscella preheater that uses the heat from the hot crude oil from the stripper and imparts to the "cold" miscella. For a 1000 ton/day plant, steam savings of ca. 700 pph are realized, or $28,000/year. Figure 10 depicts a shell and tube miscella preheater, with heat from steam ejectors.

Hexane heating. DT vapors that are not condensed in the 1st-stage evaporator will aid in heating up the solvent in the condensate from the 1st-stage evaporator and any other streams of condensate that are lower than 130 F, by installing a vapor contactor between the 1st-stage evaporator and the excess vapors condenser. For a 1000 ton/day plant and 0.9 solvent ratio, heating the hexane from 90 to 130 F would require 1500 pph of steam or $60,000/year.

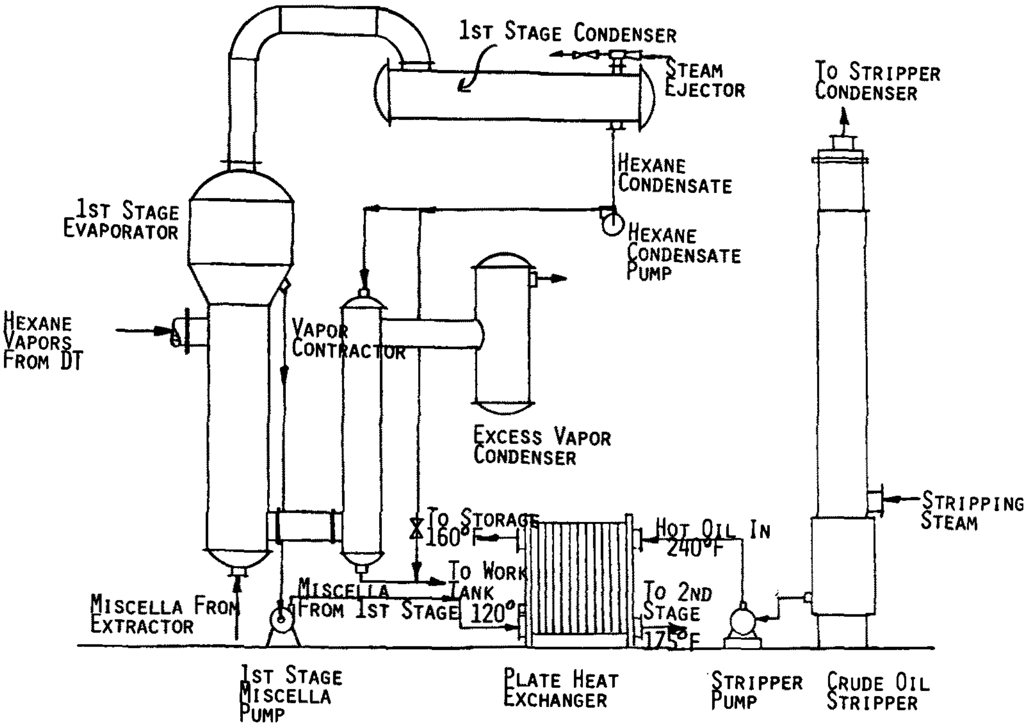

FIG. 9. Heat savings with vapor contactor and plate heat exchanger.

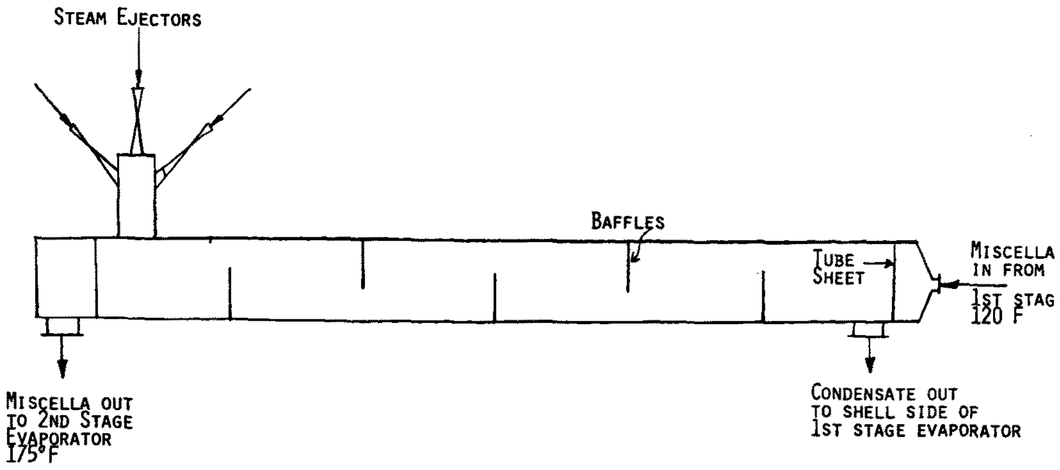

FIG. 10. Miscella preheater between 1st- and 2nd-stage evaporators.

Stripping of hexane in the final still and steam for ejectors are other consumers of steam in the solvent recovery in the extraction plant. As pointed out earlier, steam exhausted from ejectors can be used for heating miscella and also provide heat for the wastewater evaporator.

Mineral oil system. Energy consumed in the mineral oil system, final stage of the vent system in the extraction plant, is in the heater and the stripper. Rich or hexane-laden mineral oil from the absorber is normally at 90 F and needs to be heated to ca. 235 F before stripping of hexane can occur. On the other hand, lean oil from the stripper needs to be cooled before being pumped back to the absorber. This can be achieved by using a plate-type heat exchanger–interchanger, as it is commonly called. For a 20 gal/min mineral oil system, steam savings of ca. 400 pph are realized, or $16,000/year.

Finally in the recovery of solvent, refrigerated vent condensers have been added to the vent system prior to the mineral oil system. Hexane concentration in the vent gases at 90 F is 55% vs only 24% by weight at 50 F, hence a substantial amount of hexane can be recovered in refrigerated condenser prior to the vapors going to the mineral oil system.

The Gastech, made by Bendix, has a pump with selected ranges of tubes that can aid in monitoring hexane losses, i.e., at the DT discharge and at the absorber fan. Using it, one can predict quite accurately what the total solvent loss is.

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