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MASTER

**EVAPORATION
A PRIME TARGET
FOR
INDUSTRIAL ENERGY CONSERVATION**

**An Executive Briefing Report by
the U.S. Energy Research and Development Administration
Office of Industrial Energy Conservation**

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The Potential for Reducing Energy Costs

Evaporation is one of the processing industry's oldest and most widely used operations. Although it saves energy in the long run by reducing transportation and handling costs, this step is usually one of the most energy-consuming unit operations on any manufacturing site. The nation's total energy for evaporation is not known with complete accuracy; however, one recent estimate places industrial energy consumption for this purpose at 660 trillion Btu/yr, or the equivalent of 110 million barrels of fuel oil per year. Opinions from evaporator manufacturers indicate that the actual value could be as much as twice this amount.

The influence of higher fuel prices on the cost of steam has caused a dramatic increase in the expense of operating evaporators. A typical two-effect evaporator now requires about \$15 in fuel costs to remove 1000 gallons of water from a process stream. A few years ago the fuel cost for this same evaporator would have been less than \$5. By upgrading the evaporator, it is possible to greatly reduce the operating costs.

Because of the importance of energy to evaporation, even the oldest evaporators were probably at some time the subjects of economic analyses in which the energy savings were weighed against the lower capital costs and increased operating convenience of less energy-efficient systems. Since evaporator energy expenses were a much lower percentage of the total plant

operating costs in the past, these earlier economic evaluations are no longer valid.

The major criterion for past evaporator designs was minimum initial equipment cost. It was common to forgo techniques and designs that would conserve steam in view of the low energy costs of the times. The reasoning behind this philosophy was not faulty. Building and operating an evaporator in a highly energy-efficient manner does add some complexities to the design, construction, and operation of the system. The cost of evaporator hardware added to save energy normally did not offer significantly attractive paybacks. This is no longer true. Energy costs have increased radically in comparison to equipment costs (Fig. 1).

Figures 2 and 3 show the major areas of energy loss in a single-effect and a triple-effect industrial evaporation system. The single-effect evaporator shown in Fig. 2 is commonly used for highly corrosive fluids and for small capacities. In the past, if expensive materials of construction were required, the cost of additional effects was higher than the savings realized from the lowered energy use. The small capacities also increased the cost per unit of energy saved for any additional equipment installed. The new energy costs have changed this economic breakpoint. At today's energy prices, energy conservation measures can offer higher returns in existing single-effect and multieffect systems.

Figure 1

ESCALATION OF EQUIPMENT COSTS VS. IMPORTED FUEL OIL COSTS

	Imported Fuel Oil (\$/Bbl)	Marshall and Swift Equip- ment Cost Index
1973	3.29	344.1
1974	11.06	398.4
1975	11.49	444.3

Construction/Erection Costs Have Escalated at
a Rate Similar to Equipment Costs

Figure 2. Typical single-effect evaporator sources of energy loss and process flows.

Figure 1.3 Typical multi-effect evaporator, three-effect natural circulation system.

In all evaporators, further effecting, thermal or mechanical recompression and the use of heat interchange on liquid streams are likely to be economical at the new energy prices.

Table 1 compares the operating costs of one double-effect evaporator in 1967, the year it was installed, with the present, 1976, costs. The table shows that total operating costs for 1976 have increased \$715,000 over the 1967 figure. Of this total increase, \$650,000 is a direct result of higher steam costs. Only \$65,000 results from other increases.

In addition to the changing requirements for evaluating energy-conserving capital costs, many operating practices that developed during periods of low energy costs are now uneconomical.

Any evaporators that have not been reevaluated against the new energy costs are likely to be much more expensive to run than is necessary.

This report outlines for the process industry manager some of the key areas where savings in evaporation cost can be made.

Table 1.

Operating Cost Escalation for an Existing Evaporator, between 1967 and 1976

Item	Year	
	1967	1976
Total installed investment (TII):	\$340,000	
Evaporation rate:	50,000 lb water/hr	
Manufacturing costs (dollars/yr):		
Operating labor (2 man-years)	\$ 15,800 (@ \$3.80/hr)	\$ 28,300 (6.40/hr)
Supervisor (0.5 man-years)	5,400 (@ \$5.20/hr)	9,100 (8.76/hr)
Maintenance (@ 6% of investment)	20,400	36,000
General plant overhead*	16,700	28,500
Raw materials	--	--
Depreciation (@ 10% of investment)	34,000	34,000
Taxes (@ 1% of investment)	3,400	3,400
Utility costs:		
Steam (at 33,000 lb/hr)	130,000 (@ 50¢/1000 lb)	780,000 (@ \$3/1000 lb)
Cooling water (1500 gal/min)	14,200 (@ 2¢/1000 lb)	28,400 (@ 4¢/1000 gal)
Electricity (70 kWh)	3,300 (@ 6¢/kWh)	11,000 (@ 2¢/kWh)
Total manufacturing costs excluding raw material costs	\$243,200	\$958,000
Percent increase in total costs		294
Percent increase attributed to steam cost		267
Percent increase attributed to total costs minus steam cost		27

* General plant overhead = 0.58 (operating labor and supervision plus maintenance salaries).
Maintenance on labor = 0.37 maintenance costs. Return on investment (ROI) is before tax.

Options for Upgrading Evaporators

The options for upgrading existing evaporators fall within three general categories:

- o Low-investment improvements external to the evaporator: basically fine tuning of the existing hardware
- o Moderate-investment changes that normally can be authorized at the plant level such as improved heat recovery from condensates and product streams
- o Large-investment changes that normally require approval at the corporate level, such as installing additional effects or adding a vapor recompression preconcentration system.

The economics for each of these options depend heavily on the existing plant situation. If the heat in the condensate is largely wasted, for example, then the installation of flash tanks may be attractive. If, on the other hand, the bulk of the energy in the condensate is recovered at the boiler, which is not usually the case, flash tanks may not be an economical choice. Likewise, the economics of added insulation are a function of the existing insulation and of the temperature profiles in the evaporator system. The economics of adding further effects are greatly affected by the cost of the required construction materials.

There are no hard and fast rules that can be applied without economic and engineering analysis. On the basis of past evaporator design philosophies and the normal conditions found in many manufacturing processes, however, the more promising

areas of energy conservation for existing evaporators can be outlined.

Correctable Operating Factors

Because of the low investment required for fine-tuning improvements and the need to develop a base line against which to evaluate the economics of any future changes, a logical first step is to establish the best performance capabilities of an evaporator with its existing hardware.

Several correctable operating factors commonly add to energy losses in evaporators; most of them will become evident when an accurate heat and material balance is made.

Venting Rates

Noncondensibles enter the system with the feed or by way of system leaks. In multieffect evaporators, the noncondensable vapors from the vapor space of one effect collect in the steam chest of the following effect. These noncondensibles must be vented to prevent an increase in pressure and to maintain good heat transfer. Because the noncondensibles are commingled with steam, any venting beyond that required to maintain heat transfer wastes steam. Figure 4 shows the costs of steam wasted in an example 100,000 lb/hr feed rate triple-effect evaporator as a function of excess venting rate for both the old and new steam costs. If venting rates are too low, additional fresh steam is required to overcome the rise in boiling points, the decrease in heat transfer, and the loss of the sensible heat contribution to flashing. If venting is too high, the steam is lost to the atmosphere or condenser. At 100 per cent excess venting, the steam rate is increased by 450

Figure 3.4

INCREASED STEAM CONSUMPTION (lb/hr)

1,300

1,200

1,100

1,000

900

800

700

600

500

400

300

200

100

0

Steam Consumption

Steam cost at \$3 per 1,000 lb

Steam cost at 75¢ per 1,000 lb

EXCESS OF STEAM VENTING (percent)

100

200

300

Based on triple-effect evaporation

feed rate, 100,000 lb/hr at 100°F

dissolved air in feed, 30 ppm;

leakage, 25 lb/hr air/effect;

5 percent air in vented vapors. Base case =

0 percent. Curve valid for specific example only

40

35

30

25

20

15

10

5

0

STEAM COSTS RESULTING FROM EXCESS

VENTING (thousand dollars per year)

lb/hr, which raises the annual costs for evaporation by \$11,500. Excess venting losses can be minimized by converting the conventional venting method, Fig. 5(a), to the scheme shown in Fig. 5(b), which recovers the steam in each following effect and accomplishes all venting from the last effect.

Air Leakage

Air leakage raises the level of noncondensibles in the vapor and therefore (except for the last effect) requires an increase in venting rates to maintain correct temperature and pressure profile. The result is the same as that of excessive venting. Excessive air leaks can also overload the vacuum jets and increase the pressures throughout the evaporator system.

Evaporators with excessive air leakage are sometimes operated with the extra startup vacuum equipment continually in operation in an effort to maintain the vacuum (and, therefore, the capacity) of an evaporator. Although this procedure may sometimes be necessary for a short time, finding and minimizing the air leaks is much less expensive.

Fouling

Fouling of either the process or the condensing-vapor side of the heat-transfer surfaces of the evaporator decreases heat transfer. Reduced heat-transfer rates cause loss of capacity, unless the steam pressure to the first effect is raised. If the operator follows this common practice to bring the evaporator back to capacity, the increased steam pressure then causes a loss in energy efficiency because of increased condensate and

Figure ⁵ 4a. Conventional venting.

Liquid
in blur

5
Figure 4b. Stage venting
protects against excess venting
in one effect.

product heat losses. Therefore, unless heat-recovery equipment is used, the fouling cycle of an evaporator system between cleanouts can affect the amount of energy used. The last days of operation before evaporator cleanout are less energy efficient. Reduced operating time between cleanouts may show favorable economics.

Figure 6 shows the increase in steam consumption for a three-effect 10,000 lb/hr evaporator when the operator attempts to maintain capacity as the surfaces foul by increasing steam pressure to the first effect. The higher temperatures and sensible heat in condensates at the higher pressures are lost and, therefore, total energy usage increases. This curve assumes no liquid heat recovery systems are in use. A 20 per cent decrease in average heat transfer coefficients would raise the steam rate by 8.7 per cent. Liquid heat exchange and condensate heat recovery (discussed in Sec. 4, Moderate-Investment Improvements) would reduce this loss.

Maintaining the pressure profile is of utmost importance. Any deterioration of evaporation systems that results in continual operation at pressures higher than those for which the system was designed should be prevented because the higher pressure profile results in increased energy requirements unless there is extensive heat recovery. This is shown in Fig. 7 for a three-effect evaporator. Under the design conditions, the hourly steam consumption for this evaporator is 3360 lb/hr. The low steam requirements are in part a result of the relatively high temperature of the feed (180°F). If, because of condenser

Figure 3.6, Steam consumption versus
percent of clean heat transfer coefficient

if lost capacity is made up by increasing steam to first
effect and no heat recovery equipment is used.

Triple-Effect Evaporator.

10,000 lbs/hr

Evaporation Rate

STEAM CONSUMPTION (thousand lb/hr)

4.5
4.3
4.1
3.9
3.7
3.5
3.3

40 50 60 70 80 90 100

OPERATING U AS PERCENT OF CLEAN HEAT TRANSFER COEFFICIENTS

Figure 6.7 Final

pressure in last effect versus

steam consumption, if

operator raises steam

pressure to first effect to maintain

capacity.

Steam Consumption lbs/hr

4,300

4,100

3,900

3,700

3,500

3,300

1

2

3

4

Absolute Pressure at Condenser, psia

Basis

Three Effect 10,000 lbs/hr Evaporator
with No Heat Recovery for Product or
Condensates. Evaporator Feed was
180°F.

flooding, air leakage, and so forth, the pressure in the final effect increases and the steam pressure to the first effect is increased to maintain production and concentration, steam use in the evaporator body itself (exclusive of any additional steam use at the jets or increased radiation loss) will increase. If the existing design was 1.0 psia at the condenser and the vacuum reduced to 2 psia, the steam rate is increased by 13.1 per cent. Once again, this sensitivity can be reduced by product/feed interchange.

Water Dilution

Any water that leaks into the process dilutes the product and increases the amount of water to be evaporated. Possible sources of leakage are corroded heat-exchange surfaces, pump seal flushes, and leaks in the valves providing water for cleaning out the evaporator during startup and shutdown. Surprising amounts of water can be leaked into a high-vacuum evaporator by faulty mechanical pump seals. Faulty seals have been found to leak up to 0.5 gal/min, which would cause an additional steam cost of about \$6600 per year for a single-effect evaporator (at \$3 per 1000 pounds of steam). Open flush valves can dilute at rates exceeding 20 gal/min.

Separator Efficiencies

If the vapor/liquid separation efficiency is poor, product will be carried over into the condensate of the following effect. The product yield is then reduced, and the pollution load is increased. The reduction in yield wastes all the energy

expended to produce the lost product and increases the raw material costs. When scaling materials, such as tars, salts, or oils, are entrained, fouling of the heat-transfer surface of the next effect is accelerated. Plugging of the demister pads in the separator can occur, which will adversely affect the pressure profile.

Radiation and Convection Losses

The economics of adding additional insulation to an evaporator system depend directly on the temperature of each effect and the location of the unit. The amount of additional insulation that can be justified can be estimated from standard handbooks. Damaged, wet, or nonexistent insulation is more often a greater source of loss than is inadequate thickness because most evaporator bodies operate at relatively low temperatures. The new energy costs have made it worthwhile to maintain existing insulation and to consider additional insulation for areas where the temperature is above 200°F. Heat losses from 1000 sq. ft. of bare surface can exceed 500,000 Btu/hr in an outside evaporator at a surface temperature of 200°F. with a moderate wind. This is the equivalent of \$13,200 in steam costs at \$3/1000 lb. This cost can be reduced to \$1500 per year by installing only 1 in. of insulation.

Moderate-Investment Improvements

Several further options for improving the energy efficiency of existing evaporators fall short of requiring major investment. The most important of these are:

- o Improved heat recovery
- o Condensate and product flashing
- o Improved instrumentation.

Improved Heat Recovery

Figures 2 and 3 show the normal points of heat loss in evaporators. An evaporation system normally loses some energy through the hot concentrated product, condensates from the evaporator steam chests, final-effect vapor, and steam jet exhaust streams.

The new energy costs have greatly changed the economics of installing hardware to recover a portion of these losses. The decision on whether to use heat recovery is normally based on a straightforward balancing of energy cost savings vs. the capital and increased pumping costs associated with the heat exchange equipment.

When the feed is cold, it is usually the most attractive stream for recovering the low-availability heat leaving the evaporator (Fig. 8). Depending on its initial temperature, the feed stream can often be preheated by the product and/or the condensate from the intermediate effects. In all cases, the heat recovered directly replaces steam. This technique is limited eventually by the decreasing temperature difference

Figure 78
Preheating Feed with Product

between the receiving stream and the low-availability energy supplier. The required heat-transfer area eventually becomes so great that further recovery is uneconomical. Figure 9 shows the steam savings vs. the cost of added heat-transfer area for the heat exchanger to exchange hot product with cold feed, using both the old and new energy prices, and the time required for the steam savings to match the investment for one evaporator. The new energy costs have had a radical effect on the economics of heat recovery. The ability to make full use of the heat in the condensates and product, of course, is a strong function of the existing feed temperature and its properties.

Condensate and Product Flashing

The condensed steam from the steam chest of the first few effects of an evaporator still has available energy. This energy can be recovered by exchange with the feed or another, cooler stream. If there is no low-temperature stream available, then it may be economic to generate steam by flashing higher pressure condensate to the lower pressure in following effects. Figure 10 shows a flash tank system recovering steam in this manner. The applicability of this approach depends greatly on the existing condensate return conditions to the steam boiler. If the plant condensate return system is designed to conserve the available energy in the condensate, there may be a reduced incentive to recover the energy in the first effect condensate at the evaporator site. In most plants, however, the slightly

Figure 8.

Curves Derived for Triple Effect Evaporator.
 Feed Rate 100,000 lbs/hr at 100°F to Heat Exchanger
 Steam Consumption 16,000 lbs/hr (Unheated Feed)
 -- Steam at 27 psia
 Curves Valid for Specific Example Only

Installed Heat Exchanger Cost in \$
 or
 Steam Savings \$ Per Year

70000
60000
50000
40000
30000
20000
10000

10

20

30

40

50

Temperature Difference (°F) of Feed & Product Leaving Heat Exchanger

TIME FOR STEAM SAVINGS TO EQUAL INVESTMENT

$\Delta T(\text{op})$	Steam at \$3/1000 lbs.	Steam at \$0.75/100 lbs
40	3.2 yr.	8 yr.
30	1.3 yr.	5.1 yr.
20	1.1 yr.	4.4 yr.
10	1.2 yr.	5.1 yr.

Investment

Steam at \$3/1000 lbs.

Steam at \$0.75/1000 lbs.

contaminated condensate from intermediate effects is not currently reused in the boiler, and this energy is lost.

Condensate flashing will recover the energy lost by operating evaporators at higher pressures and, therefore, will decrease the sensitivity of the evaporator's energy efficiency to the pressure profile discussed in under Correctable Operating Factors.

The hot product from backward-feed evaporators* is at the pressure and temperature of the first effect and can be cooled and further concentrated by flashing to the steam chest of other effects. This procedure recovers the heat as usable steam without requiring heat-exchange surfaces. A small additional gain in efficiency results if the flashing can be staged as shown in Fig. 11.

Instrumentation and Control

An evaporator system must be instrumented adequately to provide the data necessary for evaluating system performance and to provide indicators for identifying problems affecting energy efficiency.

The economics of good instrumentation and control are difficult to document because the savings are always linked to other improvements. To evaluate and realize the savings of other improvements as discussed requires instrumentation and

* Multieffect evaporators in which the feed flow is counter current to the vapor flow are called "backward-feed." If the feed flows in the same direction as the vapor, an evaporator is called "forward-feed."

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FIGURE 10
MULTI-STAGE PRODUCT FLASH
FOR BACKWARD FEED MULTIPLE EFFECT EVAPORATOR

control at a minimum number of points (Fig. 12). Pressure, temperature, and flow indicators must be incorporated at critical areas, such as the first-stage condensate discharge line and evaporator vapor lines. Controllers allow the operator time to maintain optimum process conditions. The data obtained allow the detailed evaluations required to plan future improvements.

Required Minimum Instrumentation for Multiple-Effect Evaporator

Legend	
(PI)	= Pressure Indicator
(TI)	= Temperature Indicator
(FI)	= Flow Indicator
(DC)	= Density Control
----	= Optional Instrumentation
—	= Minimum recommended instrumentation

Large Capital Investment Modifications

All the foregoing modifications involve changes in the evaporator auxiliary equipment, maintenance of original design conditions, or both. If severalfold reductions in steam consumption are desired, more extensive changes must be made.

The options available for radically reducing steam consumption involve either recompressing the overhead vapors for reuse or using these vapors in additional effects. Often, a combination of the two approaches is desirable. Although the capital investment required for these changes is large, the energy savings are also extensive. In addition, both vapor recompression and additional effects can be used to increase capacity as well as save energy.

Vapor Recompression

The vapor leaving the evaporator contains significant heating value as latent heat of condensation. The vapor can be reused in the same evaporator body if the temperature and pressure of the vapor are increased to conditions close to those existing in the steam chest. The two most common methods for reusing all or a fraction of this vapor are thermal recompression and mechanical recompression (see Fig. 13).

Thermal Recompression. Thermal recompression (which requires the least capital of all recompression schemes) uses a steam jet booster to recompress a fraction of the vapor leaving the evaporator. The booster raises raises the pressure and temperature of the vapor to a level where the combined vapors

Vapor Recompression Methods
Mechanical or Thermal Recompression

MECHANICAL RECOMPRESSION

THERMAL RECOMPRESSION

of motivating steam and makeup steam can be used in the steam chest. The steam requirements of the evaporator are matched by mixing the low-pressure vapors with the high-pressure steam. Thermocompression normally is applied to the first effect on existing evaporators. Steam jet thermocompressors are limited in compression ratios. At compression ratios above 1.8 to 1.0, the jets reach a critical operation where instability and pressure control become troublesome.

The energy savings are a function of the available motive steam pressures, the pressure of the vapor leaving the evaporator, and the required pressure of the steam currently used for evaporation.

Steam jet thermocompressors are economical when low-pressure steam is used for the evaporator and high-pressure steam is available at the evaporator. The jet compressor replaces the existing pressure regulator or reducing valve. It can be applied to single-effect units under the foregoing conditions.

The energy savings and capital costs depend on existing evaporator conditions. Table 2 shows the steam consumption for two single-effect evaporators, both operating at atmospheric pressure in the vapor space with different required steam pressures in the steam chests. For an evaporator requiring 5 psig steam, reducing a supply steam of 100 psig through a thermocompressor can save 56.7 %. If 12-psig steam is required, only 33.3 % can be saved.

Table 2.
Steam Consumption for Single-Effect Evaporators

<u>Item</u>	<u>Evaporator</u>	
	1	2
Evaporator feed rate (lb/hr)	15,000	15,000
Evaporator capacity (lb/hr)	10,000	10,000
Evaporator pressure (psig)	0	0
Steam chest pressure (psig)	5	12
Steam rates, approximate (lb/hr)	12,000	12,000
Vapor rate to condenser (lb/hr)	10,000	10,000
Thermocompression application:		
Compression ratio	1.3	1.8
Motive steam rate at 100 psig (lb/hr)	5,200	8,000
Vapor rate to condenser (lb/hr)	3,200	6,000
Steam savings (lb/hr)	6,800	4,000
Percent steam savings	56.7	33.3

For existing multieffect units using the total amount of first-effect vapor in the second effect, the choice and location become more complex because the steam rates must be balanced. The economics, however, may still be favorable.

Mechanical Recompression. In mechanical recompression all the vapor leaving the evaporator is compressed by a positive-displacement, axial, or centrifugal compressor. The drive can be electric motor, steam turbine, or gas engine. Under the proper conditions, the mechanical energy required by the compressor is low compared to the recoverable heat values in the vapor. Compressing steam at 0 psig to 5 psig (a compression ratio of 1.34), for example, requires a theoretical energy input of 24 Btu/lb (approximately 32 Btu/lb, taking mechanical efficiencies into account) and will recover a heat value of 980 Btu/lb. The equivalent of up to 15 effects can be achieved by mechanical recompression. This favorable energy recovery must be balanced against the capital costs of the compressor. The vapor leaving the compressor is superheated, and a vapor desuperheater is necessary to maintain heat transfer rates within an existing evaporator.

If high-pressure steam is available and a demand exists for low-pressure exhaust steam, a steam-turbine-driven compressor drastically reduces the operating costs of the compressor as compared to the cost of electrically driven units. If electrical costs are low, however, electrically driven compressors

are economic. The total energy consumption is nearly identical with either drive.

Vapor recompression becomes uneconomical if high-compression ratios are required because both the capital costs and the operating costs for the compressor increase rapidly. A breakpoint occurs at a compression ratio of 1.4 - 1.5 when a multistage centrifugal compressor must be used. Figure 14 shows the net energy savings as a function of compression ratio for evaporators with 20,000 lb/hr vapor capacity, along with costs.

To limit the compression ratio, a vapor recompression evaporator normally operates with a low temperature difference between the condensing compressed vapor and the boiling liquid in the vapor body. A large-heat exchange surface is therefore required. Many older evaporators do not have sufficient heat transfer area to allow this modification. For these older evaporators (if boiling point rise is not too high), a multi-effect evaporator might be converted to parallel operation with mechanical recompression, or an additional effect with mechanical recompression might be added as a preconcentrator. This latter step will also increase capacity.

A large boiling point rise works against vapor recompression because it increases the required compression ratio. For this reason, the initial preconcentration step is usually the best candidate for mechanical recompression because boiling point rise is usually low in this stage.

The thorough evaluation of vapor recompression options is an important part of any upgrading program.

Figure 14.
Mechanical Recompression

Energy Savings and Compressor Hardware Costs for Single Effect
Evaporators Rated at 20,000/lb/hr and 60,000 lb/hr Vapor
Rate Over the Range of Compression Ratios from 1.1 to 2.0

Legend

1. Energy savings are based on the steam rate reduction at steam costs of \$3/1000 lb and electricity costs of \$0.02/kwhr
2. Compressor Hardware costs include panel board, compressor auxiliaries and driver. DO NOT include motor starters, electrical wiring, compressor installation cost and evaporator retrofit costs.

Temperature Difference Between Condensing Vapor and Boiling
Liquor $T_2 - T_1$ (Heat Transfer ΔT) No Boiling Point Rise

Installing Additional Effects

When most existing evaporation systems were selected, one of the major design evaluations was determining the optimum number of effects. As has been discussed, the change in costs makes these previous evaluations out of date.

Figure 15 shows the steam costs to the operator as a function of the number of effects. One curve is for the old steam costs of \$0.75/1000 lb. The second curve is for the new costs of about \$3/1000 lb. The savings now possible in going from one to three effects with steam at \$3 are large in comparison to those which would be realized with steam at \$0.75 (\$27.60 is now saved per 1000 gallons of water removed as opposed to \$6.90 under the old costs). Figure 15 also shows that the operator of a single-effect evaporator can return to his earlier energy costs if he replaces this evaporator with a three-effect system.

The addition of effects eventually runs into economic limitations, even at high energy prices. If the initial feed conditions and final product conditions are set by other processing considerations, the allowable temperature difference between condensing vapor and boiling liquid in each effect decreases in proportion to the number of effects. As the average ΔT for heat-transfer decreases, the heat-transfer area, and therefore the capital cost, increases. This economic balance, then, must be met. Boiling point rise as the solution is concentrated can further decrease the number of effects that would otherwise be economical.

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Figure 14

Energy Cost Vs. Number of Effects

The best location within the evaporation scheme for additional effects will depend on the capacity requirements and on the existing evaporator heat-transfer areas. When heat-transfer areas are equal the location of additional effects is not critical. When they are not equal or when the boiling points and viscosities of the solution are important factors, additional care is required in determining an optimum system. Except when heat-sensitive materials or physical area restrictions are involved, the additional stages can usually be designed into the system at the beginning or the end of the existing layout. Determining the optimum number of additional effects for an existing system may require extensive calculation time if done without the aid of a computer.

The Changing Design Rationale

The overwhelming increase in the cost of energy in relation to other evaporation costs has made energy conservation the leading concern of evaporator designers. In view of this higher priority, the following trends in evaporator design can be expected:

- o Evaporation applications that in the past used single-effect designs because of low capacity or the need for expensive construction materials will increasingly use vapor recompression as a means of improving efficiency. As a minimum, thermal recompression will be used.

- o An increased number of effects is now economical for multieffecting applications. Certain capital costs, previously prohibitive, have now become acceptable. Each evaporation system design will be analyzed more closely to define the most economical number of effects.

- o Extensive heat exchange between outgoing streams (condensate and product) and the incoming feed will be used.

- o New evaporators will be equipped with the instrumentation and measurement devices necessary to allow the operators to monitor closely the performance of operating evaporators and to minimize energy use.

- o Increased automated controls will be used to maintain optimum operation.

- o Increased maintenance is now justified to keep all parts of the evaporation system in excellent condition.

- o There will be less use of evaporation schemes that inhibit the recovery of the latent heat energy of the vaporized water.

- o Each evaporation system will be analyzed carefully for each source of energy loss, and conservation measures will be taken to the economical limit.

The manager in charge of energy conservation should plan to reevaluate all his existing evaporation systems in line with this philosophy.

ERDA Assistance

Because energy cost strongly influences the economics of evaporation, significant reductions in energy use will be made voluntarily for industrial evaporation as the required engineering studies are completed and the economics are evaluated.

To accelerate the pace of achieving the short-term energy-conservation potential through upgrading on-line evaporators, the Energy Research and Development Administration (ERDA) is making available to industry a Technology Status Report on upgrading existing evaporators. This report, prepared by specialists in the design and operation of evaporators in cooperation with major evaporator manufacturers, is written for process engineers in industries using evaporation. It contains detailed technical and economic data the process engineer needs to evaluate the energy-conservation economics of the evaporators in the manufacturing facility. This publication can be obtained from: