Capital investment costs given are necessarily approximate but are intended to include all equipment and construction costs for preparation and extraction areas. A suitable building is included for housing preparation equipment; the extraction area is sheltered but not housed. Not included are all items which might reasonably be expected to be found in an existing plant, like boilers, power stations, receiving and storage facilities, meal grinding, and office. A water cooling tower is included in the solvent plants.

In addition to screw pressing and the three solvent processes based on new equipment, two special cases are included in Table I. In the first case there is now available at a considerable reduction in initial investment reconditioned screw press equipment suitable for prepressing. For simplicity, this reconditioned equipment has been depreciated in the analysis in Column 4 at the same rate as new equipment.

In the second special case most hydraulic press operators contemplating conversion to filtration-extraction will be able to use their present rolling and cooking equipment and the building in which it is housed with practically no conversion cost. This analysis is made in Column 7 where, to demonstrate filtration-extraction to the best advantage, the investment in this equipment has been assumed to be completely written off.

Another special case not included in Table I but worthy of mention is the conversion of an existing 200-ton-per-day screw press plant to solvent extraction. The approximate capital investment for the addition of a solvent extraction plant is roughly $400,000, thereby giving a total investment for the entire prepress extraction plant of $650,000. If the processor has a plant which is out of balance with respect to dehulling and delinting equipment, there is the possibility of increased production to about 250 tons per day for this case. However the additional capacity can be utilized only if the processor has improved his competitive position to enable him to obtain more seed. This is a unique case in that it offers increased capacity at a very low cost.

Conventional rates have been used for fixed charges, labor, and utilities. The sum of fixed charges and annual costs of direct operating labor, maintenance, utilities, and solvent is the total process cost from which is substracted the cost of hydraulic press operation. Increased product value is based on 11½c per pound differential between oil and hulls. The subtracting of the differential processing cost from the increased product value gives the annual increase over hydraulic pressing in manufacturing return, to which is added depreciation to get the annual payout increase.

Conclusions

At a differential of 11½c per pound between oil and hull prices all the processes analyzed are attractive investments. Screw pressing pays off well at a lower annual investment and return, and many processors can look to screw pressing as a profitable stepping stone on the way to a prepress extraction plant.

Among the solvent processes there is little difference when they are compared on the basis of all new equipment, and choice of process will likely depend on considerations of performance and product quality. Prepress extraction based on reconditioned equipment and filtration-extraction based on existing preparation equipment, where they suit the need of the individual processor, show improved returns.

Heat Transfer

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THE flow of heat is essentially a very simple thing. If two substances of different temperatures are placed so that heat can flow from the warmer to the cooler, the rate of heat flow will be directly proportional to the temperature difference between the bodies and the cross-sectional area available for transfer and inversely proportional to the resistance interposed. Application of this simple statement is sometimes a bit troublesome.


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In a solid body the flow of heat is the result of the transfer of thermal energy from one molecule to another. This process is called conduction. The same process occurs in fluids, but since the molecules are not confined to a certain point, other processes must be considered.

In fluids the transfer of heat from one point to another may be effected by carrying the heat with the flow of the fluid. This process is called convection.

All substances are capable of radiating thermal energy in the form of electromagnetic waves and of picking up radiant energy by absorption. This is known as radiation.

Generally in industrial practice the flow of heat to be considered is from a fluid through a solid to another fluid. This involves at least two and sometimes three mechanisms of heat transfer. The heat is transferred from the fluid to the solid primarily by convection and conduction. In the case of boilers and fired heaters the radiation from the gases in the combustion zone to the solid tubes is important. Radiation is always present but often may be neglected. The heat moves through the solid by conduction and from the solid to the second fluid by convection and conduction. Heat transfer may occur either in a steady state, that is, the temperature at a given point does not vary with time or as an unsteady state where the temperature at a given point varies with time, either uniformly in a given direction or periodically increasing and decreasing. For most engineering work steady state conditions apply, and the primary concern is with conduction and convection.

Conduction is the simplest form of transfer. The basic equation for steady state unidirectional conduction is Fourier's:

$$q = -kA\ dt/dL$$

For most cases k and A are constant and L is a known constant. This may be written:

$$q = \Delta t/(L/kA)$$

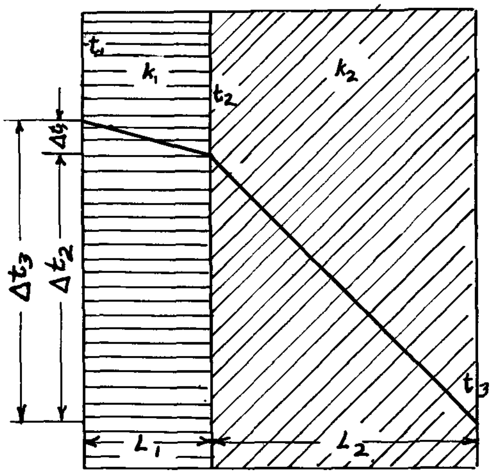
This is equivalent to the similar statement for electrical current flow:

$$I = E/R$$

Where two dissimilar bodies of equal area are present

$$(3)\quad q = \Delta t_1/L_1/k_1A_1 + \Delta t_2/L_2/k_2A_2 = \Delta T_3\ 1/(L_1/k_1A_1) + (L_2/k_2A_2)$$

By referring to Figure 1, the derivation is simply seen to follow. The quantities of heat flowing through each section per unit time must be the same (we are assuming unidirectional flow) and are given by the equation



HEAT CONDUCTION
SOLIDS IN SERIES

FIG. 1

$$q = t_1 - t_2/L_1/k_1A_1 = t_2 - t_3/L_2/k_2A_2$$

substituting $\Delta t_1 = t_1 - t_2$, etc., Equation (3) results. Using U as a total conductance

$$1/U = 1/L_1/k_1A_1 + 1/L_2/k_2A_2$$

Since L/kA represents a resistance factor, any resistance, conductance, or otherwise may be substituted to secure an over-all factor for U.

The adsorption and radiation of thermal energy has been determined to vary as the fourth power of the absolute temperature and as a specific function of the character of the surface involved. For a perfect radiator—referred to as a "Black Body"—the following equation applies:

$$q = \sigma A T^4$$

The ordinary case under consideration is concerned with radiant energy exchange between two gray bodies, surfaces which are neither perfect radiators nor reflectors. In many cases the bodies are transmitting and receiving energy from outside radiation surfaces, and to determine the amount of exchange it is necessary to determine the area of each surface which "sees" the other and to establish the radiation character (percentage of black body) of each surface. The discussion of the exact method of calculation is too complex for presentation here, and for study of calculations ofthis type you are referred to the work of Hottle (11), who developed the following simple equation:

$$q = \sigma A_{12} F_{12} (T_1^4 - T_2^4)$$

The factors A_{12} and F_{12} take into account the shape, character, and location of the surfaces.

Where transfer of heat is from (or to) a solid to (or from) a fluid by convection, the following general equation applies:

$$q = hA(\Delta t)$$

h is defined as the film coefficient of heat transfer. Three factors enter into convection transfer through a fluid:

1. Thermal circulation—mass transfer of fluid between a warmer and a cooler region,
2. Mechanical mixing of fluid,
3. Conduction of heat (similar to solids).

NOTE: In all engineering work the establishment of dimensionless parameters permits the widest possible use of data by application of the principle of similarity.

In a fluid flowing past a solid it may be demonstrated that with turbulent flow in the main body of the fluid, there is a laminar flow layer near the wall (see Figure 3). A measure of the thickness and effect of this laminar layer is given by the Reynolds Number

$$N_{re} = DV\rho/\mu$$

In cases where thermally induced convection currents are the controlling factor, it is necessary to develop an equivalent to the Reynolds Number since with zero net velocity $N_{re} = 0$. The forces acting to cause these convection currents are gravity and change in density due to heating. Therefore temperature differential and distance, L (generally vertical height), and viscosity are additional factors. These considerations lead to the development of a dimensionless parameter called Grashof's Number

$$N_{gr} = L^3\rho^2\beta g\Delta t/\mu^2$$

To express the similarity of the temperature fields in the laminar flow layer, the ratio of heat conductivity, to viscosity and specific heat are combined to form the parameter known as the Prandtl Number

$$N_{pr} = c_p\mu/k$$

The Nusselt Number gives a dimensionless parameter, using the film coefficient.

$$N_{nu} = hD/k$$

A similar parameter, the Stanton number, is often used and is very convenient where the evaluation of the size factor D in the Nusselt number is difficult. For most cases of forced convection the expression

$$N_{nu} = \phi(N_{re})^x(N_{pr})^y$$

can be used. The tables and Figure 2 give several examples.

Generally with fluids having a sharp change in viscosity with temperature, the addition of the weak function $(\mu_w/\mu_f)^{0.14}$ leads to a more satisfactory correlation.

For cases of free convection:

$$N_{nu} = \phi(N_{pr})^x(N_{gr})^y$$

The film coefficients of boiling liquids and condensing vapors are more difficult to analyze than those for single-phase operations. For the case of boiling liq-

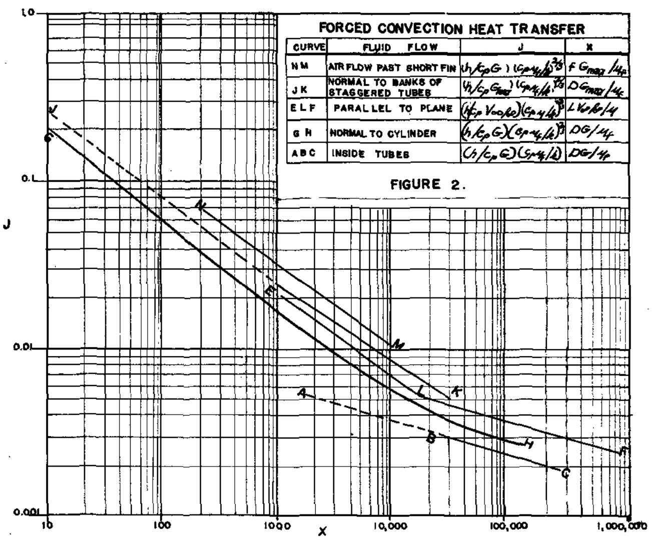


Fig. 2

uids almost all design must be based on specific data for the fluid in question and the shape of the surface.

The most satisfactory correlations have been based upon the nature of the surface, the temperature drop from the surface to the liquid, and the surface tension of the liquid.

$$h/k\sqrt{\sigma/\rho_2} = m(k\Delta T/\lambda\mu)^n$$

Myers and Katz (15) secured the following correlation for a number of liquids:

$$h_b/k\sqrt{\sigma/\rho} = 3.40 \times 10^6\ (k\Delta tL/\lambda\mu)^{2.75}$$

at boiling ranges below the critical. Other investigators secured similar results. However for a great many cases the correlation

$$h_c = (c) + (d)\ q \quad \text{applies.}$$

Constants for various liquids are given in work of Jacob and Fritz (12).

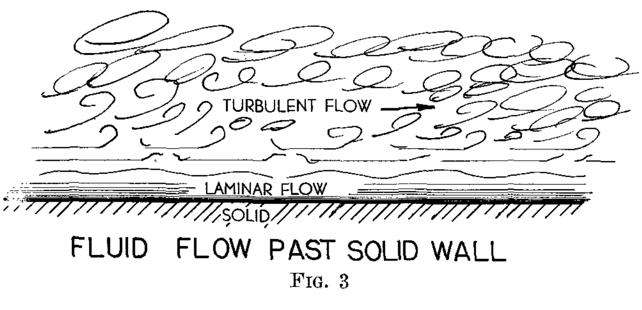
With all boiling liquids if the rate of heat flux (Δt) is increased above a certain critical value, the rate of flux drops off rapidly due to the formation of a film of superheated vapor on the surface supplying heat.

For condensing vapors two types of transfer occur, film-wise and drop-wise. In film condensation the rate is much lower than in drop-wise condensation, 2,000 for film type condensation of steam and up to 8 times as high for drop-wise condensation. It is best not to design for drop-wise condensation.

Heating Exchanger Design

The following data are needed (and are not always available) for careful heat exchanger design:

1. The quantity of heat to be transferred (fluid quantities),
2. The physical properties of the fluids. This will normally include the following:
   a) Temperature in and out,
   b) Density, specific heat, heat conductivity, viscosity, latent heat of vaporization (required only for condensation and boiling), and scale coefficients.
3. The physical limitations of the equipment:
   a) size,
   b) corrosion factors,
   c) weight.
4. The allowable pressure drop (very important in gravity flow).

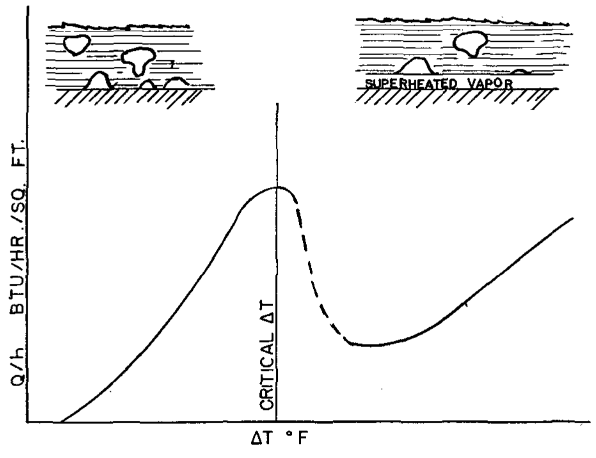


FLUID FLOW PAST SOLID WALL

Fig. 3

In calculating the heat exchanger, the following order of procedure is logical and leads to minimum work:

1. Determine inlet and outlet temperature (if a variable).
2. Determine the mean temperature drop.
3. Attempt to establish an approximate over-all heat transfer coefficient (from literature and/or experience). Include in these heat transfer coefficients the necessary fouling factors.
4. Make an approximate design for number of tubes; number of shells, baffle arrangements, tube side fluid, and shell side flow.
5. On above approximation and data calculate required nondimensional parameters.
6. Determine over-all heat transfer coefficient.
7. Determine over-all pressure drop for unit.
   Note: In cases where pressure drop is very important, revision may be required.
8. Estimate, if possible, cost of equipment and pumping costs and establish probable economic balance.
9. After design is finished, pick out best standard size if possible.
10. Turn the complete data over to exchanger manufacturer and listen carefully to his comments.



VARIATION IN TRANSFER RATES TO BOILING LIQUIDS

Fig. 4

Notes on Heat Exchanger Designs

All designs are a compromise between the technically correct (insofar as surface and exchange rates) items, economics of the individual exchangers, and coordination with the rest of the plant. Where a large number of exchangers are used, an attempt should be made to keep the number of variables at a minimum. For example, if all tubes can be made 1-in. diameter steel 12 ft. long, the operating maintenance department has to stock only 1 tube size and length. The same factor applies for all other components.

TABLE I

A Range of Values of Miscellaneous Over-all Coefficients

Type of Heat Exchanger	State of Controlling resistance		Typical Fluid	Typical Apparatus
	Free Convection U	Forced Convection U		
Liquid to Liquid	25-60	150-300	Water	Liquid to Liquid heat exchangers
Liquid to Gas (Atm. Pressure)	1-3	2-10	Water Air	Hot water radiators
Liquid to Liquid	5-10	20-50	Oil	Liquid to Liquid heat exchangers
Liquid to Boiling Liquid	20-60	50-150	Water Ammonia	Brine Coolers
Liquid to Boiling Liquid	5-20	25-60	Oil	
Gas (Atm. Pressure) to Liquid	1-3	2-10	....	Air Coolers—Economizers
Gas (Atm. Pressure) to Gas	0.6-2	2-6	....	Steam superheaters
Gas (Atm. Pressure) to Boiling Liquid	1-3	2-10	....	Steam Boilers (convection only)
Condensing Vapors to Liquid	50-200	150-800	Steam-Water	Liquid Heaters—Condensers
Condensing Vapors to Liquid	10-30	20-60	Steam Oil	....
Condensing Vapor to Liquid	40-80	60-300	Organic Vapor-Water	Condensers
Condensing Vapor to Liquid	....	15-300	Steam-Gas Mixture	....
Condensing Vapor to Gas (Atm. Pressure)	1-3	6-16	....	Steam Pipes—Air Heaters
Condensing Vapor Boiling Liquid	300-800	....	Steam-Water	....
Condensing Vapor Boiling Liquid	*50-150*	*100-200*	Steam Oil	*Still Reboilers*
Condensing Vapor Boiling Liquid	....	50-400	Steam Organic Liquids	Steam Jacketed Tubes
Condensing Vapor Boiling Liquid	40-100	....	....	Scale Forming Evaporators

U, expressed in BTU/(hr.) (sq. ft.) (°F.3 as found in practice. Under special conditions higher or lower values may be realized.

Where possible, design should be based on T.E. M.A. (1) standards for tubular heaters. This will almost always give the fabricator a break, which will be reflected in the price of the unit.

Due consideration must be given to the type of exchangers selected. With reference to ease of maintenance, scale problems have a habit of raising their ugly heads on exchangers, and some of the newer, more compact designs should be specified with caution. An exchanger which is cheap to purchase and install may be very expensive to replace or maintain in terms of labor and "down-time" costs.

All exchangers and heat exchange equipment must be designed with their service integrated to the whole plant. For example: a heat exchange unit may be ideal for the exact purpose for which designed insofar as heat transferred and pressure drop may be concerned but still may be a very poor choice when other factors affecting the complete plant are considered. If size and shape require location on special supports, up goes the cost. If it is not easily reached for maintenance, the master mechanic will be chewing nails (his, I presume). Control equipment and piping to and from the transfer unit may easily use up the available pressure drop, lowering flow rates to the point where efficient transfer no longer occurs.

The controls and piping arrangements used on heat exchange equipment should be given careful consideration at the time initial design is completed. Where two process streams are used in exchangers, the best practice generally is to bypass the controlled stream, using either bypass or three-way valve. One consideration should be mentioned on control of steam-heated equipment. The customary practice is to use a temperature-actuated control valve to regulate

TABLE II

Basic Formulas for Film Coefficients

General Formula—No Change in Phase

$(h/c_pG) = \phi(c_p\mu_f/k)^x(D\,G/\mu)^y$

This applies for turbulent flow where $N_{re} > 2100$

General solution for various cases in Figure 2

For turbulent flow in long tubes

$(h/c_pG) = 0.027\,(DG/\mu)^{-0.2}(c_p\mu_f/k)^{-2/3}(\mu_w/\mu_f)^{-0.14}$

For turbulent flow across banks of tubes. Triangular Pitch (Staggered Tubes)

$(h/c_pG)(c_p\mu_f/k)^{0.66} = 0.33\,(DG/\mu_f)^{-0.4}$

For turbulent flow across banks of tubes. Square Pitch (In Line Tubes)

$(h/c_pG)(c_p\mu_f/k)^{0.66} = 0.29\,(DG/\mu_f)^{-0.4}$

For viscous flow in long tubes

$(hD/k) = (\mu_f/\mu_w)^{-0.14} = (wc_p/kL)^{1/3}\,1.65\,(1 + 0.015\,\sqrt{N_{gr}})$

For most cases the simplified formula

$(hD/k)(\mu_w/\mu_f)^{0.14} = 2\,(wc_p/kL)^{1/3}$

For natural convection from surfaces to air the following dimensional equations apply

$h = 0.42\,(\Delta t \cdot 12/D)^{0.25}$	Horizontal Pipes.
$h = 0.40\,(\Delta t \cdot 12/D)^{0.25}$	Long Vertical Pipes.
$h = 0.28\,(\Delta t/H)^{0.25}$	Vertical Plate—Height less than 2 feet.
$h = 0.3\,(\Delta t)^{0.25}$	Vertical Plate—Height more than 2 feet.
$h = 0.38\,(\Delta t)^{0.25}$	Plates facing up,
$h = 0.2\,(\Delta t)^{0.25}$	*Plates facing down.*

For submerged coils in liquids

$(hD/k) = [(D^3\rho^2\beta\,g\Delta t/\mu_f^2)(c_p\mu/k)]^{0.25}$

When value of Grashof Number is less than 1,000, do not use. This gives high values in some cases and does not apply for agitated liquids.

For condensing vapors, film condensation, no superheat

$(hD/k) = 0.725\,(D^3\rho_f^2g\lambda/k\mu_fn\Delta t_m)^{0.25}$ Horizontal Tubes.

$(hL_s/k) = 0.94\,(L^3\rho_f^2g\lambda/k\mu_fn\Delta t_m)^{0.25}$ Vertical Tubes.

NOMENCLATURE

Symbol	Designation	Units
A	Area	Sq. ft.
A_{12}	Area Factor	None
C	Specific Heat	BTU/(lb.) (°F.)
D	Characteristic dimension in Reynolds Number, generally diameter	Ft.
d	Differential Operator	None
F_{12}	Shape Factor	None
G	Mass Velocity	lb./(sec.) (sq. ft.)
g	Acceleration due to Gravity	ft./(sec.) (sec.)
H	Height	ft.
h	Film Coefficient of Heat Transfer	BTU/(hr.) (sq. ft.) (°F.)
k	Thermal Conductivity	BTU/(hr.) (sq. ft.) (°F.)
L	Length	Ft.
N	Number (as designated)	None
P	Pressure	lbs./sq. ft.
q	Quantity of Heat	BTU
T	Absolute Temperature	°R
t	Temperature	°F
V	Velocity	ft./hr.
w	Weight Flow	lb./hr.
x,y	Factors	None
β	Volumetric Coefficient of Thermal Expansion	cu. ft./(cu. ft.) (°F.)
λ	Latent Heat of Vaporization	BTU/lb.
σ	Stefan-Boltzmann Constant	1.73×10^{-9} BTU/$_4$(hr.) (sq. ft.) (°R)
Δ	Difference	None
μ	Viscosity	lb./(sec. (Ft.)
ρ	Density	lb./(cu. ft.)
ϕ	Function	None
	Subscripts	
f	Average value for fluid	
p	Constant pressure	
w	Value at solid-liquid interface	

steam inlet pressure and a bucket trap to control the removal of condensate. The sudden discharge of the trap drops the pressure in the exchanger; the heat transfer drops, the steam valve opens, and the pressure goes up too high. This can be avoided by use of condensate receivers outside the exchanger with a level control valve, which is sized to give smooth rates of condensate flow with little effect on steam pressure in the exchanger. This is an expensive set-up but is sometimes justified. It may also be used for control by covering a portion of the surface with condensate. On all condensing units provision must be made to remove the non-condensable gases from the system.

All, and I mean all, heat exchangers should have the piping and nozzles arranged so that the tube bundle and the shell may be removed without disturbing the connecting piping and shut-off valves. (Automobile radiators, for example, are not so arranged.)

It is very desirable to have couplings installed on each inlet and outlet stream for thermometers and pressure gauges. These couplings may not always be used, but it is difficult to cut into a flowing line and install couplings when test data are required, and it is fairly easy to unplug a coupling.

The accompanying Table of Basic Formulas for Film Coefficients summarizes the required information for very elementary estimation of heat transfer coefficients for the most commonly occurring cases. It is difficult, if not impossible, to set forth in a short paper, such as this, more than the most elementary concepts. In almost all cases final design of heat transfer equipment should be made or at least checked by a specialist in the field.

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Accident Prevention in Cottonseed Oil Mills

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THE president of one of the larger aircraft corporations has said, "A good safety record, in my opinion, is the proof as well as the result of competent management." Management can have the kind of safety record it wants. In order to have a good record it is necessary to interest management first. If everyone under management is not interested, difficulties will be encountered. One disinterested person in an organization can tear down interest faster than several others can build it. It has been our observation that an employee cannot be forced to be safety-minded. If he cannot be sold on the idea, it is far better to replace him with someone who can be sold.

The following data have been taken from *Accident Facts*, published by the National Safety Council for the year 1952:

Industrial Deaths	15,000
Industrial Injuries	2,100,000
Killed in off-the-job Accidents	34,500
Accidental Deaths in the Home	29,500
Accidental Injuries in the Home	4,400,000
Motor Vehicle Deaths	38,000
Motor Vehicle Injuries	1,350,000

According to the National Safety Council, every 20 minutes four people are killed and 360 injured, with the costs amounting to $300,000 during that time.

Industry is doing something about accident prevention, so is the Department of Public Safety, but the only way to do something about home accidents is by doing such a thorough job of training men on the job that they will carry it with them to their homes and apply the principles of safety off-the-job. The Department of Public Safety is doing an excellent job of accident prevention, but they have an extremely difficult problem.

Select Your Men

The first important prerequisite in accident prevention is to select your men. I mean, really look them over. You want to select a man who is not only physically able but who is mentally capable of comprehending and carrying out instructions. The examining physician in most cases is in no better position to judge his mental condition than you are if you actually sit down and take his application. In a lot of cases however I must admit that our examining physician has been very cooperative in helping us keep from our payroll some fellow who, although physically sound, did not have the mental capacity to work safely around machinery.

When you have taken the man's application, check the references which he has given you. You will find these very helpful. Having passed him yourself, send him to the examining physician for a physical. There are various standards for physicals. Your company doctor will be glad to assist you in working out a standard to fit your needs. Our applicants are rated A, B, C, or D. A, of course, is the best and capable of doing any kind of work. Class B are those who are fit for any job but have temporary, curable or correctable defects, such as bad teeth, bad tonsils, etc. Class