(c) Graph the two individual cost factors (capital cost and power-loss cost) and the total cost as a function of the cross-sectional area *A*, and discuss the impact of increasing energy cost on the optimum obtained in part (a).

6.54 All industrial facilities have a network of piping that carries water or other liquids. According to a U.S. Department of Energy study[3], 16% of a typical facility's electricity costs are for its pumping systems. Suppose that you are considering a pumping facility having 10,000 ft to carry 600 gpm of water continuously to a storage tank. The general equation for estimating fractional pumping costs is

$$\text{Cost}\ (\$) = \frac{1}{1705}(\text{Friction Factor})\,\frac{(\text{Flow in gpm})^3(\text{Pipe length in ft})}{(\text{Pipe inner diameter in inches})^5} \times \frac{(\text{Number of hours})(\$/\text{kWh})}{(\text{Combined pump and motor efficiency as a percent})}$$

where the friction factor (based on the pipe roughness), pipe diameter, and the Reynolds number can be obtained from an engineering handbook. For most applications, the value of this friction factor will be between 0.015 and 0.0225.

(a) Using clean iron and 6-inch steel pipe (schedule 40) for pumping 70°F water, an electricity cost of \$0.05/kWh, 8,760 operating hours annually, and combined pump and motor efficiency of 70%, determine the pumping cost.

(b) With the same condition, determine the pumping cost with a 10-inch pipe.

(c) Find the current price of steel and determine the optimal size of pipe, assuming that the pumping operation would last 15 years and the savage value of the pipe at 10% of the initial investment. Assume also a discount rate of 12%.

Short Case Studies

ST6.1 Absorption chillers provide cooling to buildings by using heat. This seemingly paradoxical (but highly efficient) technology is most cost-effective in large facilities with significant heat loads. Not only do absorption chillers use less energy than conventional equipment does, but they also cool buildings without the use of ozone-depleting chlorofluorocarbons (CFCs). Unlike conventional electric chillers, which use mechanical energy in a vapor compression process to provide refrigeration, absorption chillers primarily use heat energy with limited mechanical energy for pumping. Absorption chillers can be powered by natural gas, steam, or waste heat.

- The most promising markets for absorption chillers are in commercial buildings, government facilities, college campuses, hospital complexes, industrial parks, and municipalities.
- Absorption chillers generally become economically attractive when there is a source of inexpensive thermal energy at temperatures between 212°F and 392°F.
- An absorption chiller transfers thermal energy from the heat source to the heat sink through an absorbent fluid and a refrigerant. The absorption chiller accomplishes its refrigerative effect by absorbing and then releasing water vapor into and out of a lithium–bromide solution. Absorption chiller systems are classified by single-, double-, or triple-stage effects, which indicate the number of generators in the given system.
- The greater the number of stages, the higher is the overall efficiency of the system. Double-effect absorption chillers typically have a higher first cost (but a significantly lower energy cost) than single-effect chillers, resulting in a lower net present worth.

Some of the known economic benefits of the absorption chiller over the conventional mechanical chiller are as follows.[4]

[3] "Energy Tips, Reduce Pumping Costs Through Optimum Pipe Size," Office of Industrial Technologies, Energy Efficiency, and Renewable Energy, U.S. Department of Energy.

[4] *Source*: EcoGeneration Solutions™ LLC. Companies, 12615 Jones Rd., Suite 209, Houston, Texas, 77070 (http://www.cogeneration.net/Absorption_Chillers.htm).

- In a plant where low-pressure steam is currently being vented to the atmosphere, a mechanical chiller with a coefficient of performance (COP) of 4.0 is used 4,000 hours per year to produce an average of 300 tons of refrigeration.
- The plant's cost of electricity is \$0.05 per kilowatt-hour. An absorption unit requiring 5,400 lb/hr of 15-psig steam could replace the mechanical chiller, providing the following annual electrical cost savings:

$$\text{Annual Savings} = 300 \text{ tons} \times (12{,}000 \text{ Btu/ton}/4.0) \times 4{,}000 \text{ hrs/yr} \times \$0.05/\text{kWh} \times 1 \text{ kWh}/3{,}413 \text{ Btu} = \$52{,}740$$

Suppose you plan to install the chiller and expect to operate it continuously for 10 years. What would be the maximum amount that can be invested in installing the chiller with the capacity as described above? If the energy cost were expected to increase at an annual rate of 10%, how would your answer change? Assume $i = 10\%$.

ST6.2 Automotive engineers at Ford Motor Co. are considering the laser blank welding (LBW) technique to produce a windshield frame rail blank. The engineers believe that, compared with the conventional sheet metal blanks, LBW would result in a significant savings as follows.

1. Scrap reduction through more efficient blank nesting on coil.
2. Scrap reclamation (weld scrap offal into a larger, usable blank).

The use of a laser-welded blank provides a reduction in engineered scrap for the production of a window-frame rail blank.

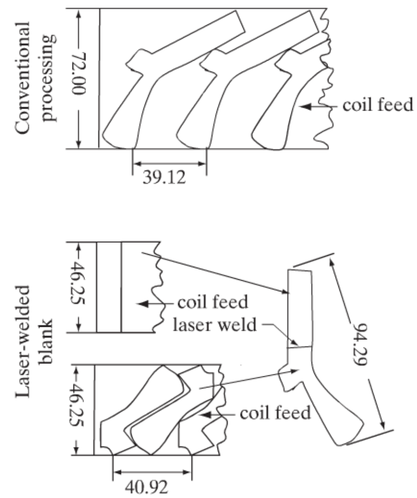

Figure ST6.2

TABLE ST6.2	**Blanking Method**	
Description	**Conventional**	**Laser Blank Welding**
Weight per blank (lb/part)	63.764	34.870
Steel cost/part	\$14.98	\$8.19
Transportation/part	\$0.67	\$0.42
Blanking/part	\$0.50	\$0.40
Die investment	\$106,480	\$83,000

On the basis of an annual volume of 3,000 blanks, Ford engineers have estimated the financial data given in Table ST6.2.

The LBW technique appears to achieve significant savings, so Ford's engineers are leaning toward adopting it. Since the engineers have had no previous experience with LBW, they are not sure whether producing the windshield frames in-house at this time is a good strategy. For this windshield frame, it may be cheaper to use the services of a supplier that has both the experience with, and the machinery for, laser blanking. Ford's lack of skill in laser blanking may mean that it will take six months to get up to the required production volume. If, however, Ford relies on a supplier, it can only assume that supplier labor problems will not halt the production of Ford's parts. The make-or-buy decision depends on two factors: the amount of new investment that is required in laser welding and whether additional machinery will be required for future products. Assume a lifetime of 10 years and an interest rate of 16% to recommend the best course of action. Assume also that the salvage value at the end of 10 years is estimated to be insignificant for either system. If Ford considers the subcontracting option, what would be the acceptable range of contract bid (unit cost per part)?

ST6.3 The proliferation of computers in all aspects of business has created an ever-increasing need for data-capture systems that are fast, reliable, and cost-effective. One technology that has been adopted by many manufacturers, distributors, and retailers is a bar-coding system. Hermes Electronics, a leading manufacturer of underwater surveillance equipment, evaluated the economic benefits of installing an automated data-acquisition system into its plant. The company could use the system on a limited scale, such as for tracking parts and assemblies for inventory management, or it could opt for a broader implementation by recording information that is useful for quality control, operator efficiency, attendance, and other functions. All these aspects are currently monitored, but although computers are used to manage the information, the recording is primarily conducted manually. The advantages of an automated data-collection system, which include faster and more accurate data capture, quicker analysis of and response to production changes, and savings due to tighter control over operations, could easily outweigh the cost of the new system. Two alternative systems from competing suppliers are under consideration.

- **System 1** relies on handheld bar-code scanners that transmit radio frequencies. The hub of this wireless network can then be connected to the company's existing LAN and integrated with its current MRP II system and other management software.
- **System 2** consists primarily of specialized data terminals installed at every collection point with connected bar-code scanners where required. This system is configured in such a way as to facilitate phasing in the components over two stages or installing the system all at once. The former would allow Hermes to defer some of the capital investment, while becoming thoroughly familiar with the functions introduced in the first stage.

Either of these systems would satisfy Hermes' data-collection needs. They each have some unique elements, and the company needs to compare the relative benefits of the features offered by each system. From the point of view of engineering economics, the two systems have different capital costs, and their operating and maintenance costs are not identical. One system also may be rated to last longer than the other before replacement is required, particularly if the option of acquiring system 2 in phases is selected. Discuss many issues to be addressed in making the right choice.

ST6.4 A Veterans Administration (VA) hospital is to decide which type of boiler fuel system will most efficiently provide the required steam energy output for heating, laundry, and sterilization purposes. The current boilers were installed in the early 1950s and are now obsolete. Much of the auxiliary equipment is also old and in need of repair. Because of these general conditions, an engineering recommendation was made to replace the entire plant with a new boiler plant building that would house modern equipment. The cost of demolishing the old boiler plant would be almost a complete loss, as the salvage value of the scrap steel and used brick was estimated to be only about $1,000. The VA hospital's engineer finally selected two alternative proposals as being worthy of more intensive analysis. The hospital's annual energy requirement, measured in terms of steam output, is approximately 145,000,000 pounds of steam. As a rule of thumb for analysis, 1 pound of steam is approximately 1,000 Btu, and 1 cubic foot of natural gas is also approximately 1,000 Btu. The two alternatives are as follows.

- **Proposal 1.** Replace the old plant with a new coal-fired boiler plant that costs $1,770,300. To meet the requirements for particulate emission as set by the Environmental Protection Agency, this coal-fired boiler, even if it burned low-sulfur coal, would need an electrostatic precipitator, which would cost approximately $100,000. The plant would last for 20 years. One pound of dry coal yields about 14,300 Btu. To convert the 145,000,000 pounds of steam energy to the common denominator of Btu, it is necessary to multiply by 1,000. To find the Btu input requirements, it is necessary to divide by the relative boiler efficiency for the type of fuel. The boiler efficiency for coal is 0.75. The price of coal is estimated to be $55.50 per ton.
- **Proposal 2.** Build a gas-fired boiler plant with No. 2 fuel oil, and use the new plant as a standby. This system would cost $889,200 and have an expected service life of 20 years. Since small household or commercial gas users that are entirely dependent on gas have priority, large plants must have an oil switch-over capability. It has been estimated that 6% of 145,000,000 pounds of steam energy (or 8,700,000 pounds) would come about as a result of the switch to oil. The boiler efficiency with each fuel would be 0.78 for gas and 0.81 for oil, respectively. The heat value of

natural gas is approximately 1,000,000 Btu/MCF (thousand cubic feet), and for No. 2 fuel oil, it is 139,400 Btu/gal. The estimated gas price is \$9.50/MCF, and the price of No. 2 fuel oil is \$1.35 per gallon.

(a) Calculate the annual fuel costs for each proposal.

(b) Determine the unit cost per steam pound for each proposal. Assume that $i = 10\%$.

(c) Which proposal is the more economical?

ST6.5 The following is a letter that I received from a local city engineer:

> Dear Professor Park:
>
> Thank you for taking the time to assist with this problem. I'm really embarrassed at not being able to solve it myself, since it seems rather straightforward. The situation is as follows:
>
> A citizen of Opelika paid for concrete drainage pipe approximately 20 years ago to be installed on his property. (We have a policy that if drainage trouble exists on private property and the owner agrees to pay for the material, city crews will install it.) That was the case in this problem. Therefore, we are dealing with only material costs, disregarding labor.
>
> However, this past year, we removed the pipe purchased by the citizen, due to a larger area drainage project. He thinks, and we agree, that he is due some refund for salvage value of the pipe due to its remaining life.
>
> Problem:
>
> - Known: 80′ of 48″ pipe purchased 20 years ago. Current quoted price of 48″ pipe = \$52.60/foot, times 80 feet = \$4,208 total cost in today's dollars.
> - Unknown: Original purchase price.
> - Assumptions: 50-year life; therefore, assume 30 years of life remaining at removal after 20 years. A 4% price increase per year, average, over 20 years.
>
> Thus, we wish to calculate the cost of the pipe 20 years ago. Then we will calculate, in today's dollars, the present salvage value after 20 years' use, with 30 years of life remaining. Thank you again for your help. We look forward to your reply.
>
> Charlie Thomas, P.E.
>
> Director of Engineering
>
> City of Opelika

After reading this letter, recommend a reasonable amount of compensation to the citizen for the replaced drainage pipe.