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ECONOMIC ASSESSMENT OF BACKFITTING POWER PLANTS WITH CLOSED-CYCLE COOLING SYSTEMS

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Prepared for U.S. Environmental Protection Agency
Contract No. 68-03-0430
ROAP No. 21AZU-019
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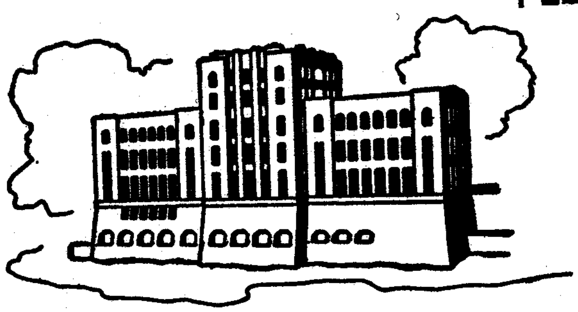

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Iowa Institute of Hydraulic Research
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ABSTRACT

This report describes a detailed methodology for the assessment of the economic consequences of backfitting electric power plants, currently operating on open-cycle or once-through cooling systems, with conventional closed-cycle cooling systems. In particular, four different types of closed-cycle cooling systems have been investigated: 1) mechanical-draft crossflow wet cooling towers, 2) natural-draft crossflow wet cooling towers, 3) cooling ponds, and 4) spray canals. Representative thermodynamic models have been used to reproduce the operating characteristics of different types of turbines, condensers, and cooling systems in order to estimate the operational penalties associated with backfitting. Available capital and operating cost information has been compiled and used, in conjunction with the levelized annual cost method of accounting, to evaluate the total differential cost of power production resulting from the backfit.

Since the operating consequences, such as replacement capacity, energy losses, excess fuel consumption, and water requirements depend upon the size and type of existing turbines, fluctuations in power demand, size of the cooling system, and variations in the meteorological conditions at the site, detailed analyses of backfitting are best performed with the aid of a digital computer. Suitable computer programs have therefore been developed and presented. To facilitate rapid assessment of differential costs, however, a large number of representative calculations have been performed and are presented graphically. In particular, the results for three different types of conventional turbines and four different geographical sites have been obtained for

a range of cooling-system sizes, and they are depicted in suitable plots. Once the various unit costs of replacement capacity, energy loss, fuel, and water are known, these results can be used to evaluate the cost to be assessed against backfitting. Representative values of the unit costs are included in the report.

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ACKNOWLEDGEMENTS

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SECTION I

CONCLUSIONS

The general methodology for the economic evaluation of backfitting power plants with closed-cycle cooling systems has been presented. The following major conclusions can be drawn from the study.

1. The computer programs developed here can be used to assess the total differential cost of backfitting power plants with any of the following closed-cycle systems:

   Mechanical-draft crossflow wet cooling towers,
   Natural-draft crossflow wet cooling towers,
   Cooling ponds, and
   Spray canals.

   The programs accept as input data turbine size and characteristics, size of cooling system, fluctuations in power demand, variations in site meteorological conditions, and economic parameters. The thermodynamic and performance models used to evaluate the operating consequences such as capacity and energy losses, excess fuel consumption and water requirements are representative of those in current use. The overall accuracy of the economic predictions therefore depends largely on accurate projection of the capital cost of the cooling system and on the unit costs associated with capacity replacement, make-up energy and fuel. While an effort has been made to incorporate the most recent estimates for capital costs of cooling systems, it is also recognized that these costs vary over a wide margin, particularly in the cases of cooling ponds and spray canals, due to unforeseen problems associated with construction at particular sites.

2. The overall complexity of the backfit analysis is such that it does not allow the use of simplified models and construction of simple nomographs for general use. Nevertheless, it has been possible to obtain a comprehensive set of results from selected model applications which will enable a rapid evaluation of the total cost of backfitting when some of the basic characteristics of the power plant, the cooling system, and the site are known. A considerable amount of generality has been achieved by (a) assuming that the power demand remains constant at the full-throttle value of the turbine; (b) presenting in a graphical form only the basic quantities such as capacity loss, energy loss, excess fuel consumption and water evaporation as functions of cooling-system size in a convenient format, so that these quantities can be evaluated for any given nameplate capacity of the turbine and size of the cooling system; (c) estimating the capital cost of the cooling system in terms of its physical size and not in terms of thermodynamic properties of the system; and (d) performing the calculations for three different types of turbines and for four climatically different sites. The presentation of the results in this form is particularly useful since the influence of using different values of the economic parameters, such as capital cost of cooling system, unit costs of replacement capacity and energy, etc., can be investigated with ease. The use of these results has been illustrated by means of a hypothetical example for each of the four closed-cycle cooling systems.

3. The actual performance of the affected power plant or unit in open-cycle operation can be investigated by modifying the basic procedures to include the variations in the water-body temperature. Such an alteration was not, however, considered in the present study since it would have resulted in a loss of generality which was considered essential for the presentation of the results in

simple graphical form.

4. The present study indicates that the total cost of backfitting, in mills/kW-hr of energy delivered, depends mainly on the capital cost of the cooling system, the capital cost associated with the replacement of lost capacity, the operating costs of peaking plants built to replace the energy losses, and the excess fuel consumption of the affected units due to higher back-pressure operation resulting from the backfit. Under the assumption of full-throttle power demand, however, the excess fuel consumption is much smaller than would actually result from a variable power demand, but there is a corresponding increase in the energy losses. Comparison between the detailed calculations using the computer programs with realistic power demand variations and those performed using the graphical results with full-throttle power suggest that the total costs calculated by the two methods may differ only by a few percent. This small difference gives added confidence in the use of the results presented graphically.

5. The sensitivity of the total cost of backfitting to the factors listed above suggests that great care must be taken in estimating the following for each application:

   Capital cost of the cooling system,
   Unit cost of replacement capacity,
   Unit cost of replacement energy,
   Unit cost of fuel, and
   Fixed charge rate.

   As indicated earlier, the first of these quantities can be found readily from the data presented in this report, but an on-going check must be maintained in order to ascertain the impact of inflation within the industry. Needless to say, the most reliable and up-to-date information can best be obtained directly from the manufacturers and construction engineers.

A considerable amount of variation in these costs can be expected from site to site, but for cooling towers the estimates presented here appear to be reliable within about 15 percent for applications up to 1980. The remaining factors listed above depend upon the particular utility situation. However, if capacity and energy losses are to be made up by means of gas-turbine peaking units, the unit costs will be of the order of $100/kW for capacity replacement and 10 mills/kW-hr for energy replacement based upon 1975 estimates.

6. In the hypothetical examples analyzed in detail in the text, where the power plant characteristics as well as the site meteorological conditions were approximately the same for all four closed-cycle cooling systems, the total excess unit costs of backfitting (in mills/kW-hr) were found to be

Mechanical-draft crossflow wet cooling towers	:	0.582
Natural-draft crossflow wet cooling towers	:	0.916
Cooling ponds	:	0.666
Spray canals	:	0.694

These costs can not, of course, be compared on an absolute scale since the size of each cooling system was chosen arbitrarily, and no attempt was made to verify an "optimum" size. Nevertheless, since each size is realistic and since the same values of the unit costs of replacement capacity, replacement energy, fuel, water, and fixed charge rate have been used, the total costs listed above give a good general indication for each type of cooling system.

7. The computer programs as well as the graphical results of the present study can be used to make an independent assessment of the cost of backfitting a given power plant or unit at a known site with a range of sizes of the four different types of closed-cycle cooling systems.

8. Finally, the assessment of backfitting costs can best be made for any particular situation by using the computer models given in the appendices. No interpolation error will be involved, and inclusion of the actual design power loading for the specific situation may be made (instead of the assumed "full-throttle" design loading implicit in the figures of this report). The programs are designed to accomodate a design loading composed of two power levels (one of which is the maximum) and can be easily extended to more.

SECTION II

RECOMMENDATIONS

Four major recommendations are made on the basis of the present study:

1. As far as possible, the computer programs presented in this report should be used to independently assess the economic consequences of backfitting power plants with closed-cycle cooling systems and to compare the estimated total costs with those evaluated by other methods. Rapid estimates of backfitting costs can also be made by using the representative set of graphical results, which will, however, involve a certain amount of approximation.

2. The utilization of the computer programs allows the economic analysis of backfitting to be based upon the actual design power loading instead of the full-throttle loading assumed in the graphical results. Design power loadings with more than two defined levels of power output can be analyzed with slight modifications of the program. The actual performance of the affected unit during open-cycle operation can also be modeled by incorporating expected variations in the water-body temperature in the program.

3. The validity of any economic analysis of cooling systems will depend upon the proper selection of individual cost factors and constraints. Among the more important site-specific considerations is the requirement for land and its availability. While the example problems for cooling towers in this report have land

requirements based on noise attenuation, other criteria such as construction area and plume recirculation may be more applicable.

4. An on-going survey should be maintained to determine the prevailing and expected costs of cooling systems, unit costs of replacement capacity, replacement energy, fuel, and water, as well as the fixed charge rate, so that the general methodology developed for this study can be updated periodically.

SECTION III

INTRODUCTION

Following the recent enactment of "environmental" legislation (The Federal Water Pollution Control Act Amendments of 1972), the Environmental Protection Agency has been charged with the task of developing guidelines and standards of performance for steam electric power plants. Originally, the EPA's proposed §304 guidelines and §306 standards [1,2,3,4] suggested that, except for the power plants receiving exemption under §316(a), all plants operating with open-cycle cooling systems should be backfitted with closed-cycle systems by the year 1983. However, these guidelines soon met with much opposition, and in ensuing adversary hearings, a set of revised guidelines were constructed [5]. In accordance with these new EPA guidelines, the thermal discharges are to be limited according to the following schedule [6:§423.13 ℓ(1)-(6),m]:

A. There shall be no discharge of heat from the main condensers except

(1) "Heat may be discharged in blowdown from recirculated cooling water systems provided the temperature at which the blowdown is discharged does not exceed at any time the lowest temperature of recirculating cooling water prior to the addition of the make-up water.

(2) "Heat may be discharged in blowdown from recirculated cooling water systems which have been designed to discharge blowdown water at a temperature above the lowest temperature of recirculated cooling water prior to the addition of make-up water providing such recirculating cooling systems have been placed in operation or are under construction prior to the effective date of this regulation (July 1, 1981).

(3) "Heat may be discharged where the owner or operator of a unit otherwise subject to this limitation can demonstrate

that a cooling pond or cooling lake is used or is under construction as of the effective date of this regulation to cool recirculated cooling water before it is recirculated to the main condensers.

(4) "Heat may be discharged where the owner or operator of a unit otherwise subject to this limitation can demonstrate that sufficient land for the construction and operation of mechanical draft evaporative cooling towers is not available (after consideration of alternate land use assignments) on the premises or on adjoining property under the ownership or control of the owner or operator as of March 4, 1974, and that no alternate recirculating cooling system is practicable.

(5) "Heat may be discharged where the owner or operator of a unit otherwise subject to this limitation can demonstrate that the total dissolved solids concentration in blowdown exceeds 30,000 mg/l and land not owned or controlled by the owner or operator as of March 4, 1974, is located within 150 meters (500 feet) in the prevailing downwind direction of every practicable location for mechanical draft cooling towers and that no alternate recirculating cooling system is practicable.

(6) "Heat may be discharged where the owner or operator of a unit otherwise subject to this limitation can demonstrate to the regional administrator or State, if the State has NPDES permit issuing authority, that the plume which must necessarily emit from a cooling tower would cause a substantial hazard to commercial aviation and that no alternate recirculated cooling water system is practicable. In making such demonstration to the regional administrator or State the owner or operator of such unit must include a finding by the Federal Aviation Administration that the visible plume emitted from a well-operated cooling tower would in fact cause a substantial hazard to commercial aviation in the vicinity of a major commercial airport.

(m) "The limitation of paragraph (l) of this section shall become effective on July 1, 1981.

B. These new guidelines shall have both the exclusions implicit in the above paragraphs and the additional exclusions outlined here:

units on line before January 1, 1970, are excluded;
units of 500MW or less on line before January 1, 1974, are excluded;
units of less than 25MW are excluded; and
units in a system of 150MW or less are excluded.

The above guidelines are to be effective July 1, 1981, as indicated in paragraph (m) above; however, there are provisions of deferral of compliance until July 1, 1983, if system reliability would be seriously affected.

The present study is concerned with the development of a detailed methodology for the evaluation of the cost of backfitting a plant or unit currently operating on open-cycle with a closed-cycle cooling system. Four different closed-cycle systems are considered:

Mechanical-Draft Crossflow Wet Cooling Towers,
Natural-Draft Crossflow Wet Cooling Towers,
Cooling Ponds, and
Spray Canals.

It is recognized that a large number of conflicting factors enter into the estimation of the cost of backfitting. Since many of these are highly site-dependent, it is not possible to arrive at general conclusions applicable to all utility situations. However, the purpose here has been to develop a method which is flexible enough to take these factors into consideration so that when they are prescribed or determined the cost can be estimated.

The evaluation of the additional costs against the power generated is important to the utility since it provides a basis for determining the necessary rate increases. Of major concern in the backfitting operation is the fact that the capacity of the unit will be reduced by the amount of power consumed within the closed-cycle system and by penalties that may be incurred by requiring adjustments in the operating characteristics of the unit, the main factor being the increase in the turbine exhaust pressure. This lost capacity must be replaced either by adding new capacity at the same site or elsewhere, or by operating other units at higher levels.

The major factors to be considered in the economic assessment of backfitting an existing unit are:

1. The cost of installing the closed-cycle system, including materials, labor, site acquisition and preparation;
2. The plant downtime for hook-up and testing;
3. The provision of additional generating capacity to replace the lost capacity;

4. Operation and maintenance costs of the cooling system;
5. Operation and maintenance costs of replacement capacity; and
6. Additional cost of power generation due to decrease in plant efficiency or limitations occasioned by the use of the closed-cycle system.

It will be clear that the first three of these are capital costs incurred at the time of backfitting while the last three are costs recurring over the remaining period of plant life. When these factors have been determined and the cost of borrowing the required capital expenditure are known, it is a simple matter to find the total cost, in mills per kilowatt-hour, to be charged against the actual power delivered after the backfit operation. The work described herein is concerned primarily with the evaluation of the various factors listed above. It is of course possible to design a closed-cycle cooling system, regardless of whether it is a cooling tower, pond, or spray canal, which is sufficiently large to reproduce, very nearly, the performance of the once-through system being used at present. Such a system will obviously be expensive, at least from a first-cost point of view, and the various factors enumerated above will undoubtedly intervene and dictate a somewhat smaller closed-cycle system, requiring less operating and maintenance expenses. If the cost of backfitting is to be assessed in a realistic manner, it is then obvious that a range of sizes must be considered.