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European Dry Cooling Tower Operating Experience

J. G. DeSteese
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March 1976

Prepared for the Energy Research and Development Administration under Contract E(45-1)-1830

Battelle
Pacific Northwest Laboratories

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EUROPEAN DRY COOLING TOWER OPERATING EXPERIENCE

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March 1976

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1.0 SUMMARY

Interviews were held with representatives of major plants and equipment manufacturers to obtain current information on operating experience with dry cooling towers in Europe. This report documents the objectives, background, and organizational details of the study, and presents an itemized account of contacts made to obtain information.

Plant selection was based on a merit index involving thermal capacity and length of service. A questionnaire was used to organize operational data, when available, into nine major categories of experience. Information was also solicited concerning the use of codes and standards to ensure the achievement of cooling tower performance. Several plant operators provided finned-tube samples for metallographic analysis.[a] Additionally, information on both operating experience and developing technology was supplied by European technical societies and research establishments.

Information obtained from these contacts provides an updated and representative sample of European experience with dry cooling towers, which supplements some of the detailed reviews already available in the literature. In addition, this study presents categorized operating experience with installations which have not been reviewed so extensively, but nevertheless, have significant operational histories when ranked by the merit index.

The contacts and interviews reported in this survey occurred between late March and October 1975. The study was motivated by the expressed interest of U.S. utility industry representatives who expect European experience to provide a basis of confidence that dry cooling is a reliable technology, applicable, when necessary, to U.S. operating requirements.

(a) The results of metallographic analyses on these samples are discussed in a separate report (Reference 6) dealing specifically with corrosion in cooling systems.

1.1 CATEGORIZED OPERATING EXPERIENCE

Nine categories of specific operating experience were addressed by the questionnaire. Table 1-1 summarizes the principal experience characterization of the 19 plants reviewed in this study.

With three exceptions, the plants visited represent a selection of installations with significant operating histories as suggested by heat rejection capability and service life. The list includes air-cooled heat exchangers and condensers used by utility and private power plant operators, and in the petrochemical, process and steelmaking industries. The categorization in Table 1-1 is for the purpose of showing the range and nature of experience arising from diverse applications and service conditions. Reference to this characterization made without the qualifications and circumstances discussed in the following sections of this report may lead to a false perspective. Overall experience in each category can be summarized as follows.

1.1.1 Failure Modes

Although the questionnaire included this category, it is not contained in Table 1-1 because no incidence of gross cooling system failure was reported. This results from the modularity of all-dry cooling systems, which permits isolation of malfunctioning components and their repair without perturbing the overall system function.

If corrosion and freeze-induced tube failures are considered separately, failure experience appears to be at the subcomponent level. Most events are in the nuisance category and require, at the worst, nonroutine repair or maintenance. In the case of Heller systems, small leaks occur in seals applied to connections in the cooling water circuit. GEA installations tend to exhibit occasional failures of fan motors, gears and blades.

TABLE 1-1. Categorized Operating Experience of Visited Plants[(a)]

Plant	Heat Rejection (10^{-6} Btu/hr)	Installation Data	Merit Index[(b)]	Cooling System	Corrosion	Freezing	Maintenance Frequency	Fouling	Atmospheric Effects	Environmental Impact	Rationale for Dry Cooling
Gyöngyös	2x476 + 2x905	1969-73	9760	Heller		M	I	A M	N	R	W
Rugeley	587	1961	7900	Heller	A S		I		N	R	E
Pietrafitta	2x197	1958	7090	GEA		M		A M		R	W
Wolfsburg	4x243	1961-72	6800	GEA					M	D	W
Ibbenbüren	645	1967	3900	Heller	A N		I	A S	M	D R	W
Utrillas	668	1970	3340	GEA							W
Port Jerôme	158 + 193 + 31	1967	3056	GEA	A N		I	A M	M	R	L
Dudelange	110	1956	2090	GEA				A M		R	W
Bremen	183 + 62	1968	1715	GEA						D	L
Hausham	160	1962	2080	GEA		S	I	A S	S	R	W
Dormagen	147	1964	1700	GEA			I	A M		R	W
Dunaújváros	106	1961	1490	Heller		M	I	A S		R	W E
Gelsenkirchen	2x40	1957-62	1240	GEA	A M, C N		I	A S, C S		R	W
Sindelfingen	30 + 38 + 51	1961-72	1090	GEA		S	I	A S		D R	W L
Ludwigshafen	112	1967	920	GEA	A N		I	A S	M	R	L
Vienna	96	1967	860	Heller						D	L
Godort	80	1965	800	GEA				A M		R	W
Gütersloh	11	1937	380	GEA				A M		R	W
Pignataro Majori	8	1972	32	Plastic Tube					M		E

(a) In descending order of Merit Index.
(b) Heat Rejection capability x years of service [(10^{-6} Btu/hr)yr] corrected for plant downtime when this information was available.

A - Airside
C - Condensate Side
D - Design objective to avoid environmental impact of evaporative system
E - Experimental facility
I - Increase above average
L - Local requirements which exclude alternate cooling methods
M - Moderate
N - Noticeable
R - Reverse Impact
S - Severe
W - Water cost and/or availability

1.1.2 Plant Availability

This is a corollary of the failure modes and is absent from Table 1-1 for the same reason. None of the operators interviewed in this study reported an incident in which plant availability was influenced by the condition or capacity of the dry cooling system.

1.1.3 Corrosion

GEA and Heller-type systems resist both internal and air-side corrosion under design operating conditions and in many undesirable environments. The severe air-side corrosion at Rugeley is exceptional and was created by unusual local conditions, which are now recognized and preventable. Other corrosion as noted is trivial to moderate in extent but is not expected to decrease life expectancy of the affected components. In the Federal Republic of Germany, galvanized steel heat exchangers are generally preferred for applications in which resistance to corrosion is required for decades.

1.1.4 Freezing

Dry cooling systems of both principal types have accumulated enough freezing experience to provide empirical knowledge of avoidance procedures. The most important freeze-prevention technique appears to be the training of operating personnel to recognize ambient conditions which lead to freezing.

The GEA counterflow condenser (Dephlegmator) is an important component for freeze prevention in direct condensing systems. Variable fan speed in forced-draft units and louvers in natural draft towers, in addition to sector isolation, flow rate control and coolant bypass, are available to avoid the problem of freezing. Based on European experience, therefore, a modern dry cooling installation can be designed with appropriate regard for ambient conditions to eliminate the prospect of freezing in all but the most unusual operating conditions.

The single plastic tube facility reviewed in this study showed a remarkable and intrinsic resistance to freeze damage. The elasticity of the plastic tubes accommodated the increase in volume of the frozen coolant and returned to normal size without rupture when the coolant melted. In the future, this may provide the ultimate in freeze protection and result also in substantial reduction in system cost.

1.1.5 Maintenance Frequency

Under most design conditions, both direct and Heller-type cooling systems show a high reliability and maintenance costs below those of equivalent evaporative systems. Routine maintenance includes cleaning the air-side of the heat exchanger, lubrication of motors and gears, repair of seals and other subcomponent monitoring and adjustment. With the exception of Rugeley, air-side fouling is the major cause of above-average maintenance requirements of the plants indicated in Table 1-1. Rugeley, as noted previously, is an unusual case of air-side corrosion causing the escalation of maintenance and repair costs.

1.1.6 Fouling

Air-side fouling appears to be the most common experience factor of the plants reviewed in this study. Fouling material of many kinds appears to be present in the environments of nearly all installations and is deposited on tubes and fins as cooling air flows through the heat exchanger. At some plants, the effect is continuous and severe enough that cleaning frequency is determined by the degree to which heat rejection capability has been reduced. In most installations, the tendency for fouling is eliminated by routine cleaning. The severe fouling conditions of Ibbenbüren may not have occurred had routine cleaning been practiced in the early days of operation.

If fouling is allowed to accumulate or if the rate of deposition is high, the Heller-Forgó aluminum heat exchanger appears to be less amenable to cleaning than are galvanized steel fin tube assemblies. Galvanized steel heat exchanger elements are more robust and can be cleaned effectively with high pressure water jets. The aluminum fins of the Forgó design appear to trap fouling material more readily and are relatively soft and less resistant to mechanical deformation. As a result, Forgó heat exchangers are cleaned by compressed air or low pressure water, with generally only partial effectiveness. At Ibbenbüren, the fouling material remaining after all cleaning attempts has caused a permanent reduction in heat transfer capability.

From early indications at the Pignataro Majori test station, finless plastic tube heat exchangers may prove to be relatively immune to fouling.

1.1.7 Atmospheric Effects

Reduced heat rejection capability and recirculation are noted in several cases as a result of wind effects. Recirculation has been a problem in the past under some conditions. This tendency is being reduced in modern design and can be considered to be less important today. The use of wind flow modeling techniques during the design phase (as for Utrillas) provides a choice in siting, height and proximity to other structures, which minimizes wind effects and recirculation. Forced-draft systems are naturally less sensitive to wind effects and the trend to tall towers reduces the magnitude of the problem in natural draft systems.

Rain appears to slightly improve the heat rejection performance of GEA systems, as a result of deluge or evaporative spray effects on the surface of wetted fin tubes in the bundles. The horizontal delta arrangement typical of the GEA system offers a larger surface exposed to rain than that of the vertically-oriented delta of the Heller-Forgó system. Rain and fog can degrade natural draft by cooling the air mass inside the tower.

1.1.8 Environmental Impact

Dry cooling systems generally have less environmental impact than does the balance of the plant. In Table 1-1, the dry cooling installations indicated with a 'D' in the Environmental Impact column were specified partially or wholly because of the potential objectionable environmental influence of alternate evaporative systems. An outstanding conclusion to be drawn from this study is that the environment impacts dry cooling systems more severely than vice-versa. Atmospheric effects influence heat rejection capability and, in some cases, undesirable recirculation. Pollution and other airborne material cause air-side fouling and corrosion.

1.2 RELEVANCE TO U.S. CONDITIONS

European dry cooling experience can be considered encouraging to prospective users in the U.S. A basis of confidence has been accumulated in both service life and plant size. The Gyöngyös complex is a significant technical achievement and demonstrates the viability of the Heller-Forgó indirect-dry cooling in large capacity installations. The essentially trouble-free, five-year history of the Utrillas plant is a particularly significant demonstration of a reliable, large-capacity, direct-condensing, air-cooled heat rejection system using GEA technology. Several similarities in siting and service conditions suggest that the excellent experience with the Utrillas plant is a preview, at approximately half-scale, of satisfactory performance of the Wyodak dry cooling system.

A majority of the 19-plant sample discussed in this report show the rationale for installing dry cooling equipment to be based on water cost and availability. With growing competition for water allocations and the current trend in legislated siting requirements, U.S. utilities will soon face problems associated with economic access to water similar to those already existing in Europe today.

1.3 POTENTIAL FOR IMPROVED OPERATION

An objective of this study was to define the potential for improved operation. It is evident that European manufacturers are actively advancing the technology of already highly developed dry cooling systems.

Classic problem cases, such as corrosion at Rugeley and fouling at Ibbenbüren, are well documented. The wealth of accumulating experience in Europe shows these now-predictable problems to be isolated historical events which are avoidable with current design and operational practices.

Experience gained in Europe has provided the basis of design and operational practices which reduce corrosion, freezing, fouling and atmospheric effects to an insignificant level. Research underway in the laboratories of manufacturers should lead to further improvements in corrosion protection, hybrid cooling systems, fan noise and efficiency. Plastic tube heat exchangers are under investigation and may offer system simplification and cost reduction possibilities in the future. Improved operation will result from the application of these developments and the refinement of already proven practices.

1.4 OVERVIEW

This study adds support to conclusions expressed or implied by previous reviews, that European dry cooling experience demonstrates a mature and reliable technology, supplied by competent and innovative manufacturers, in a competitive market. With the emphasis on the diminishing economic availability of cooling water, the criteria which create the rationale for air-cooled equipment in Europe will be applicable under similar circumstances in the U.S. European dry cooling experience should encourage U.S. operators to install dry cooling systems when the same criteria apply in U.S. situations.

2.0 INTRODUCTION

This report describes interviews and correspondence with European specialists undertaken to determine the current status of operating experience with dry cooling towers in Europe.

2.1 SUBTASK OBJECTIVES

The objectives of this subtask were to summarize current operating experience of air-cooled heat exchangers in Europe, to identify relevance to U.S. conditions, and to define the potential for improved operation based on this experience.

2.2 BACKGROUND

European industrial areas confront problems of cooling water availability, pollution and environmental impact sometimes several years ahead of the time when similar conditions mature in the United States. As a result, many European air-cooled power plant heat rejection systems have already been in service long enough to provide operational histories relevant to anticipated future conditions in the U.S.

Air-cooled heat rejection systems will be used in large U.S. power plants when combinations of economic, technical, environmental, social and political criteria favor dry cooling systems over competitive methods. Even after such factors come to bear, it is anticipated that a level of reluctance to apply air-cooled systems may still persist as a result of most utility management having no direct operating experience. Recognizing this tendency, representatives of the U.S. utility industry have expressed interest in European operation of air-cooled heat exchangers as a basis for future confidence in the technology.

Operating experience with the larger European dry cooling systems is covered extensively in the available literature. Some of the smaller systems have been reviewed in relatively less detail and others appear to be entirely neglected. In terms of thermal load rating, many of these smaller systems appear at first sight as too small to be relevant to utility interests in the U.S. However, many small plants have been in service for relatively long periods, compared with the current average lifetime of the larger plants. As both thermal rating and service life are factors which provide a base of confidence in the technology, both factors were used to screen large and small plants for inclusion in this survey.

2.3 SUBTASK ORGANIZATION

The subtask was accomplished in two phases. Phase I included preparation of the questionnaire, visits to the largest plants of interest in western Europe, contacts with manufacturers and associations and a review of literature. Phase II consisted of a series of 14 plant interviews selected on the basis of data collected in Phase I.

A questionnaire prepared at the Pacific Northwest Laboratory (PNL) consisted of twelve Operating Experience Interview Worksheets. A sample blank copy is attached as Appendix A. Two sheets solicited general information; ten additional worksheets addressed the following specific experience categories:

1. Failure Modes
2. Corrosion
3. Freezing
4. Maintenance Frequency
5. Fouling Propensity
6. Wind Effects
7. Recirculation
8. Availability
9. Codes and Standard Used to Ensure Performance
10. Environmental Impace

Information was received from the following sources:

1. utilities and private power plants,
2. petrochemical and process industries,
3. manufacturers of air-cooled heat exchangers,
4. users of special-duty high-capacity heat exchangers,

5. technical societies and trade associations,
6. research institutions.

Phase I interviews were held at the following locations:

1. CEGB Rugeley Station, Rugeley, England
2. Volkswagenwerk AG Power Plant, Wolfsburg, Germany
3. Preussag AG Power Plant, Ibbenbüren, Germany
4. Union Termica S.A. Power Station, Utrillas, Spain
5. Plastic Tube Cooling Tower Test Facility, Pignataro Majori, Italy.

Phase I contact with equipment manufacturers included:

1. GEA - Gesellschaft für Luftkondensation mbH, Bochum, Germany
2. Balcke-Dürr AG, Bochum, Germany
3. Italimpianti, Genoa, Italy.

In addition, a review of recent literature was made and contact was established with the following associations:

1. VGB - Technische Vereinigung Grosskraftwerksbetreiber e.V. (Technical Association of Large Power Plant Operators)
2. VDEW - Vereinigung Deutscher Elektrizitätswerke (German Power Plant Association)
3. DECHEMA - Apparatebau (Association of Process Equipment Manufacturers for the Chemical Industry).

As noted in the following sections, some interviews were held by both PNL and Battelle-Frankfurt (BF) investigators. The PNL investigator travelled in Europe to help organize and coordinate the BF effort and to field-test the English-language questionnaire for adequacy. Information on new technology and samples for metallographic analysis were also obtained.

In Phase II, the following series of 14 plant interviews was conducted:

1. Daimler-Benz AG Power Plant, Sindelfingen, Germany
2. Hausham Power Plant, Hausham/Schliersee, Germany
3. City of Vienna Wasteburning Plant, Vienna, Austria
4. Steel Works Power Plant, Dunaujváros, Hungary
5. Jurij Gagarin Power Plant, Gyöngyös, Hungary
6. ARBED-Steelworks Power Plant, Dudelange, Luxembourg
7. BASF Chemical Works Power Plant, Ludwigshafen, Germany
8. Esso Refinery Power Plant, Port Jeróme, France
9. City of Bremen Wasteburning Plant, Bremen, Germany
10. Benzene Refinery Condenser, Gelsenkirchen, Germany
11. Erdöl Chemie Petrochemical Power Plant, Dormagen, Germany
12. Wirus-Werke Power Plant, Gütersloh, Germany
13. Shell Refinery Condenser, Godort, Germany
14. Pietrafitta Power Plant, Perugia, Italy

These plants were selected from a list of installations compiled in Phase I as plants worthy of interest indicated by the merit index ranking method.

3.0 LITERATURE SURVEY

As part of the Phase I effort, leading scientific journals pertaining to energy, thermodynamics, heat and mass transfer, and allied subjects were surveyed to provide a bibliography of predominantly European-source material. The survey covered the period from 1969 to the first quarter of 1975. Two major manufacturers of dry cooling equipment (GEA and Balcke-Dürr) courteously placed their bibliographic material at our disposal. Appendix B contains an alphabetically-ordered bibliography of over 150 publications retrieved from these sources. This bibliography demonstrates the existence of an extensive body of reference material on European dry cooling technology and experience.

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4.0 PHASE II PLANT INTERVIEW SELECTION

All but one of the dry cooling tower installations visited in Phase I were obvious choices, representing the largest in western Europe. The emphasis of interviews with plant management was to update the already extensive literature documenting operation at these sites.

A parallel activity in Phase I was the selection of mostly smaller plants (Gyöngyös and Pietrafitta were important exceptions) with sufficient dry cooling experience to interest U.S. observers and warrant personal visitation. Interviews with management personnel at these plants were undertaken in Phase II.

U.S. utility representatives who feel they have a limited basis for confidence in dry cooling technology have emphasized several objections to accepting favorable evidence from foreign sources and other industries. The objections include:

1. Foreign power plants are much smaller than those planned in the U.S.; thus, full-scale experience is lacking.
2. Favorable experience from relatively small power plants in Europe is aided by moderate climate, winter peaking, and less costly maintenance. It is, therefore, not totally demonstrated under equivalent U.S. conditions.
3. Operating experience derived from other industries, especially the petrochemical industry, reflects different philosophies of design, maintenance and amortization, leaving room for doubt about relevance to utility operating conditions.

A merit-index method of rating the significance of operating experience was used to maximize its value to U.S. utilities. The merit index (I) is the product,

$$I = T \cdot S$$

where

T = Thermal rating of cooling station (Btu/hr x 10^{-6})

S = Service life of cooling station (years)

With three exceptions, plants with I > 800 were chosen to permit a review of the most significant operational histories. In general, the larger capacity cooling systems are newer. Plants with long service records are generally of smaller capacity; however, they possess reasonably high merit indices by virtue of their age. By giving equal weight to size and longevity an attempt was made to distinguish operational problems associated with plant size from long-service problems, such as corrosion and maintenance.

Exceptions to the I > 800 criterion were made in three cases, as noted in the following sections, to accommodate aspects of unique experience which broaden the scope of this review.

4.1 SURVEY OF DRY COOLING EQUIPMENT ORIGINATING IN THE FEDERAL REPUBLIC OF GERMANY

In view of the variety of operators and the large number of locations where dry cooling equipment is operated, German manufacturers were approached for information on dry cooling equipment they had supplied to industrial customers in the petrochemical, process, steelmaking, and power plant sectors. The emphasis on German-origin equipment was decided by program funding and logistic constraints. Manufacturers considered in the survey were:

1. Balcke-Dürr AG
   a) Bochum Plant
   b) Ratingen Plant
2. GEA-Gesellschaft für Luftkondensation mbH, Bochum
3. Halberg Maschinenbau GmbH, Ludwigshafen
4. Theodor Wulf, Kühlerwerksbau, Waltrop
5. Zschocke-Werk, Kaiserslautern
6. Konvekta-Werk, Ziegenhain
7. Gottfried Bischoff KG, Essen
8. Stillich & Schmöcker, Berlin
9. Kuhlerfabrik Länger u. Reich, Stuttgart

10. Süddeutsche Kühlerfabrik Julius Fr. Bahr, Stuttgart

11. Borsig GmbH, Berlin

12. Gutehoffnungshütte, Sterkerade

13. Rheiner Maschinenfabrik Windhoff AG, Werk Neuenkirchen

These manufacturers were requested to supply the following information for each installation:

1. location
2. installation date
3. equipment nature and purpose
4. thermal capacity rating
5. temperature range and mass flow of media involved
6. gross heat transfer area
7. tubing and fin materials
8. module dimensions.

This survey included German equipment supplied to Austria, France, Italy, the Netherlands, Spain, and the United Kingdom.

The long list of manufacturers found in industrial handbooks suggests the illusion of a diversity of equipment which would be difficult to compare. However, many of the above manufacturers specialize in subcomponent equipment (heat exchanger elements, fans, structures, etc.) and others assemble components manufactured elsewhere. The survey showed that German dry cooling technology represented by the products of Balcke-Dürr and GEA are the most significant and form a reasonable basis for selecting plants which provide a representative sample with a broad range of experience.

Table 4-1 contains a listing of European dry cooling installations from which Phase II interview selections were made. Plants are organized in general categories and are shown with descriptive data, including the merit index as defined above.

TABLE 4-1. European Dry Cooling Installations Reviewed for Phase II Interview Selection

No.	Location	Medium to be Cooled	Mean Temperature of Medium (°F)	Mean Temperature of Air (°F)	Draft Type F-forced N-natural	Tube Characteristics E = Elliptic F = Fin G = Galvanized R = Round S = Steel T = Tube	Thermal Rating (10^{-6}.Btu/h)	Medium Mass Flow (Lbs/h)	Year of installation	Merit Index (10^{-6}x Thermal Ratingx Years)	Remarks
Air cooled heat exchanges in the Petrochemical Industry											
1	Redestillations-Gemeinschaft, Gelsenkirchen	Benzene vapor	160	68	F	ET, F - GS	2x40	560 000	1957-62	1240	Condenser for redistilled benzene
2	Rheinische Olefin Werke, Wessling b. Koeln	Water	150	80	F	ET - S	49	2 461 500	1960	735	Cooler for quenching water in fractional distillation scrubber
3	Esso-Raffinerie, Koeln	Water	240	95	F	RT - S, F - Al	24	238 200	1960	360	Cooler for quenching water in fractional distillation scrubber
4	Edison Milan, Italy	Steam	185	86	F	ET - S	9	9 410	1961	126	Condenser for process steam
5	Shell Raffinerie, Ingolstadt, Donau	Gasoline water mixture	158	86	F	ET - S	39	498 076	1962	507	Cooler for gasoline-water mixture in fractionating column
5	Shell Raffinerie Ingolstadt, Donau	Heavy-oil	230	86	F	RT - S	17	167 900	1962	221	Heavy oil cooler
7	Gelsenberg Mobiloil, Neustadt, Donau	Steam	185	95	F	ET - S	14	14 556	1963	168	Steam condenser in steam - driven fractionating column
8	Purfina Raffinerie, Milan, Italy	Superheated steam	217	86	F	RT - Monel, F - Al	7	7 227	1965	70	Process steam condenser
9	Shell Raffinerie, Hamburg	Water	162	79	F	ET - S	60	1 111 000	1965	600	Water cooler
10	Shell Raffinerie, Hamburg	Steam-gas mixture	181	79	F	ET - S	92	92 674	1965	920	Cooler in steam-driven fractionating column
11	Shell International Petroleum, Billingham, GB	Water	212	68	F	RT - S, F - Al	15	206 806	1967	120	General cooler in refinery
12	ICI Mond Division, Runcorn, GB	Water	212	73	F	ET - S	37	219 952	1967	296	Cooler for quenching water in fractional distillation scrubber
13	Croydon Gasworks, Croydon, GB	Water	100	75	F	RT - S, F - Al	9	451 010	1967	72	Water cooler
14	Grangemouth Raffinerie, GB	Steam	300	70	F	RT - S, F - Al	12	13 569	1969	72	Condenser for process steam
15	Union Kraftstoffe, Wesseling b. Koeln	Steam	140	77	F	RT - S	39	44 586	1969	234	Condenser for process steam
16	Oesterreichische Mineraloelverwaltung, Vienna	Gasoline steam mixture	203	82	F	ET - S	54	55 727	1969	324	Steam condenser in steam driven fractionating column
Air cooled heat exchangers in the process industry											
17	Bayer, Leverkusen	Water	91	?	F	No information	11	393 400	?	?	Water cooler
18	Holzwerk Baehre, Baehre	Steam	212	?	F	No information	23	22 040	?	?	Condenser for process steam
19	von Roll AG, Zuerich, CH	Steam	302	?	F	No information	127	137 530	?	?	Condenser for process steam
Air cooled heat exchangers in the steel industry											
20	Kloeckner Werke, Bremen	Water	?	?	F	No information	23	?	1968	161	Water cooler
21	Rheinstahl, Hattingen	Steam	?	?	F	No information	119	?	1969	714	Condenser for process steam
22	Bochumer Verein	Water	84	68	F	T - Cu	21	1 433 333	1957	378	Water cooler in compressor unit
23	Roechlingsche Eisenwerke, Saar	Water	129	77	F	T - S	21	1 588 148	1960	315	Cooler in continuous casting unit
24	Phoenix Rheinrohr, August Thyssen Huette	Water	90	63	F	T - S	71	3 970 000	1961	994	Cooler in compressor unit
25a	Salzgitter Huettenwerk, Salzgitter	Steam	417	86	N	T - S	165	204 540	1969	990	Steam condenser in L-D converter
25b	Salzgitter Huettenwerk, Salzgitter	Steam	417	86	F	T - S	99	122 682	1967	792	Steam condenser in bessemer unit
26a	August Thyssen Huette	Water	99	70	F	T - S	123	3 255 290	1968	861	Cooler in compressor unit
26b	August Thyssen Huette	Water	212	86	F	T - S	78	2 161 388	1963	936	Cooler in slab rolling mill plant
26c	August Thyssen Huette	Water/steam	493	90	F	T - S	195	268 875	1970	975	Multi-phase cooler in compressor
27	August Thyssen Huette, Werk Schwelgern	Steam	212	86	F	T - S	131	135 061	1971	524	Steam condenser in blast furnace
28	Hoogovens, Netherlands	Steam	485	80	F	T - S	579	789 904	1967	4632	Steam condenser in blast furnace
Condenser units in power plants or backpressure turbines in other situations											
29a	Stadt Iserlohn	Steam	?	?	F	?	44	48 522	1968	308	Condensate cooling
29b	Stadt Iserlohn	Steam	?	?	F	?	60	66 166	1973	120	Condensate cooling
30	Stadtwerke Kassel	Steam	?	?	F	?	54	60 211	1970	270	Condensate cooling
31	Stadtwerke Oberhausen	Steam	?	?	F	?	25	28 150	1971	100	Condensate cooling
32a	ARBED, Dudelange, Luxemb.	Steam	?	55	F	T - S	52	57 344	1959	832	Backpressure turbine condenser
32b	ARBED, Dudelange, Luxemb.	Steam	104	55	F	RT, F - Cu	110	110 200	1956	2090	Condenser in industrial power plant
33	Pietrafitta Power Plant, Perugia, Italy	Steam	97	57	F	ET, F - GS	2x197	2x192 640	1958	7090	Utility power plant
34	Horremer Brikettfabrik, Horrem b. Koeln	Steam above atmosph. press.	302	57	N	No information	40	44 080	1958	680	Condensate from turbine used in process as pressurized water
35	Kraftwerk Hausham	Steam	95	50	F	ET, F - GS	160	201 600	1962	2080	Condenser in industrial power plant
36a	Daimler Benz, Sindelfingen	Steam	104	64	F	ET, F - GS	30	30 240	1961	440	Residual steam condenser in industrial combined power and heating plant
36b	Daimler Benz, Sindelfingen	Steam	104	64	F	ET, F - GS	38	40 992	1963	500	Residual steam condenser in industrial combined power and heating plant
36c	Daimler Benz, Sindelfingen	Steam	104	64	F	ET, F - GS	51	54 880	1972	150	Residual steam condenser in industrial combined power and heating plant
37	BASF, Ludwigshafen	Steam	95	50	F	ET, F - GS	112	112 000	1967	920	Residual steam condenser in industrial combined power and heating plant
38	Erdoelchemie, Dormagen	Steam	112	52	F	ET, F - GS	147	168 000	1964	1700	Condenser in industrial power plant
39a	Esso Refinery, Port Jerome, France	Steam	131	85	F	ET, F - Al	158	159 040	1967	1264	Condensers in refinery power plant
39b	Esso Refinery, Port Jerome, France	Steam	131	85	F	ET, F - Al	193	192 640	1967	1544	Condensers in refinery power plant
39c	Esso Refinery, Port Jerome, France	Steam	131	85	F	ET, F - Al	31	31 360	1967	248	Condensers in refinery power plant
40a	Stadtwerke Bremen Wasteburning plant	Steam	401	68	F	RT, F - GS	183	183 680	1968	1280	Condensate from turbine used in process as pressurized water
40b	Stadtwerke Bremen Wasteburning plant	Steam	257	68	F	RT, F - GS	62	62 720	1968	435	Condensate from turbine used in process as pressurized water
41	Erdoelchemie, Worringen b. Koeln	Steam	113	59	F	No information	2x152	2x147 228	1969	2x910	Condensate from turbine drive for compressors
42	Total Chimie, France	Steam	140	77	F	No information	335	330 600	1970	1676	Condensate from turbine drive for compressors
43	Danube Steelworks, Dunaújváros, Hungary	Steam	91	50	N	RT, F - Al	106	7 934 400	1961	1490	Heller System
44	Power Plant, Gyöngyös, Hungary	Steam	91	50	N	RT, F - Al	2x476 +2x905	2x20 938 000 +2x46 284 000	1969-73	9760	Heller System

5.0 PHASE I INTERVIEWS

This section contains a review of plant interviews held as part of Phase I activities. When a plant to be visited was previously well documented, the emphasis of the interview was on updating the account of operating experience contained in the most recent literature. This review describes plant visits in the chronological order of their occurrence.

5.1 DRY COOLING EQUIPMENT AT CEGB RUGELEY POWER STATION, RUGELEY, ENGLAND

Date of Visit: March 25, 1975

Participants in the Discussion:

Mr. E. Vaughan-Williams, Site Superintendent

Mr. E. L. Fuller, Deputy Station Superintendent (Station A)

Mr. J. W. Williams, Operations Superintendent (Station A)

DeSteese - PNL

5.1.1 General Remarks

The dry cooling equipment at Rugeley Station is associated with Unit No. 3 of the five-unit, 600-MWe Station A. The balance of Station A (4 x 120 MWe) units are evaporatively-cooled with makeup water taken from the nearby River Trent. Adjacent to Station A is Station B consisting of two 500-MWe units which are also evaporatively-cooled, with two natural draft towers per unit. The spatial distribution of the nine cooling towers and the two stations is illustrated in Figure 5.1-1.

Unit No. 3 is rated at a peak capacity of 120 MWe, but is run typically at about 80 MWe. Heat rejection is accomplished by the Heller-Forgó system with aluminum tubes of 99.5% purity and all aluminum plate-type fins and water boxes. The unit was commissioned in 1961 and has been operated continuously other than scheduled downtime for maintenance and repair. The English Electric Company was associated as a licensee with the Transelektro Hungarian Trading Company for the construction of the Heller-Forgó equipment.

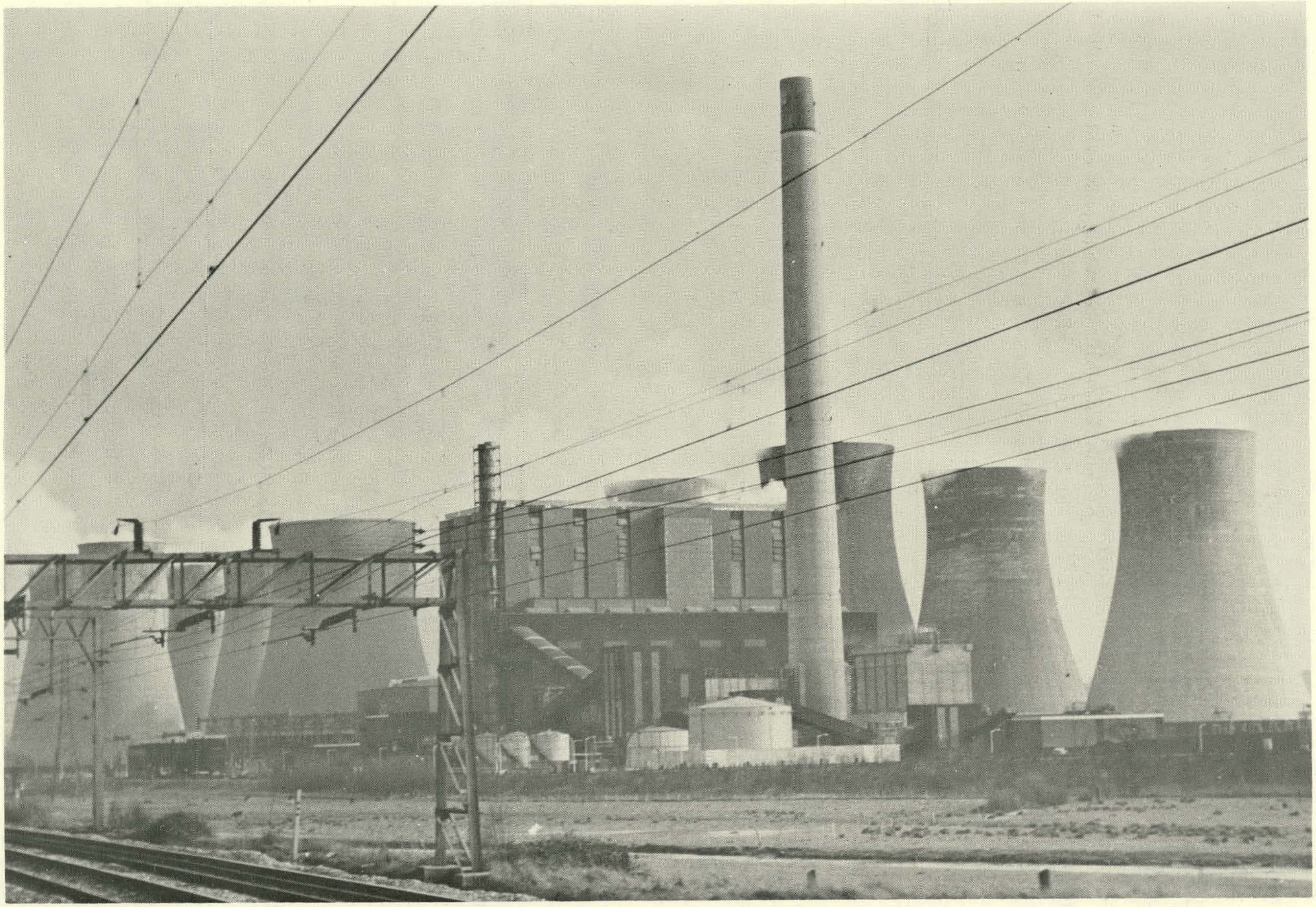


FIGURE 5.1-1. Rugeley Power Station

Overall operational experience has been consistent with design expectation except for a severe and costly air-side corrosion problem. An adequate supply of water is available at this site for evaporative cooling and the dominant motivation to construct the dry tower was to advance the technology and gain operational experience. At the time of its construction, the Rugeley dry cooling tower was the largest in the world.

The dry cooling tower at Rugeley has been reviewed extensively in the literature.(1-5) In 1970, Rossie provided a particularly full description of the system, which, with the exception of additional corrosion experience, remains valid today.(1) The following discussion supplements and updates Rossie's review. A sample of the Forgó finned-tube assembly was kindly supplied by Mr. Fuller and was brought back to PNL for metallographic analysis. The results of this work are reported in Reference 6.

5.1.2 General Operational Data

Unit No. 3 is rated at 120 MWe with steam conditions of 1000°F and 1500 psi, and 1000°F reheat at 400 psi. A design turbine back pressure of 1.3 inches Hg with a 52°F ambient air temperature is achieved by the circulation of condensate-quality cooling water at 62,000 gpm, three percent of which provides the boiler feedwater. A direct contact spray condenser is used to condense the exhaust steam from the turbine. The system provides a design ITD of 35°F between saturated steam temperature and ambient air temperature.

Unique multi-port, rotary-plug, sector valves are used to isolate sectors of the tower for partial load operation, and filling and draining procedures. An opinion of the plant management expressed at this interview was that the Rugeley dry tower would have been easier to control in bad weather if louvers had been fitted. Approximately 8.9 MWe, representing 7.3 percent of the full load rating, is required to operate auxiliary equipment in Unit No. 3. The design heat rejection load of the tower is 5.87×10^8 Btu/hr, providing an experience merit index over 13.5 years operation of approximately 7900. According to this method of ranking experience, Rugeley is among the world's three highest ranking plants using the Heller system (after Gyöngyös, Hungary and Razdan, USSR).

5.1.3 Air-Side Corrosion Experience

Severe air-side corrosion in the heat exchanger has been a continuous problem. The need for corrosion protection was not indicated by previous experience in Hungary with the Heller-Forgó system. The Rugeley experience results from environmental exposure.

A coal mine and an ash-sintering plant are in close proximity to the cooling towers and prevailing winds at the site carry products of air pollution from the industrial city of Birmingham. By virtue of being on an island, Rugeley and other relatively inland regions of England experience low-level salt carryover from coastal areas. Rain in England is fairly frequent and the Rugeley dry tower is in the path of drift from adjacent evaporative towers (Figure 5.1-2) under prevailing wind conditions.

Hydrochloric acid corrosion cells are created by the combined effects of moisture, chlorides and other airborne pollutants working into crevices between the tubes, spacer collars and fins of the Forgó heat exchanger. Corrosion appears after about 12 months of operation and results in deterioration of the fins and eventual penetration of the tube walls. Attack is accelerated when a section is out of service, the rate of corrosion being estimated as 20 times faster than that under normal operation.

This situation was tolerated by phased retubing as leaks appeared in the coil sections. At the same time, research into the problem was conducted by CEGB and the English Electric Company. In 1969, this research resulted in the selection of an epoxy coating as the best method of corrosion prevention, as reported by Rossie.(1) An epoxy resin "Araldite-961A" was specified and used in conjunction with a strontium chromate inhibitor.

In restrospect, this solution would have proven quite satisfactory. However, at the time epoxy dip-coated coil elements were being installed, an innovative change in the fin design was specified. The new design offered an approximate two percent increase in heat rejection and eliminated the spacer collar between fins. Fins were spaced, in the new design, by a star-pattern foot formed on the fin and around the tubes.

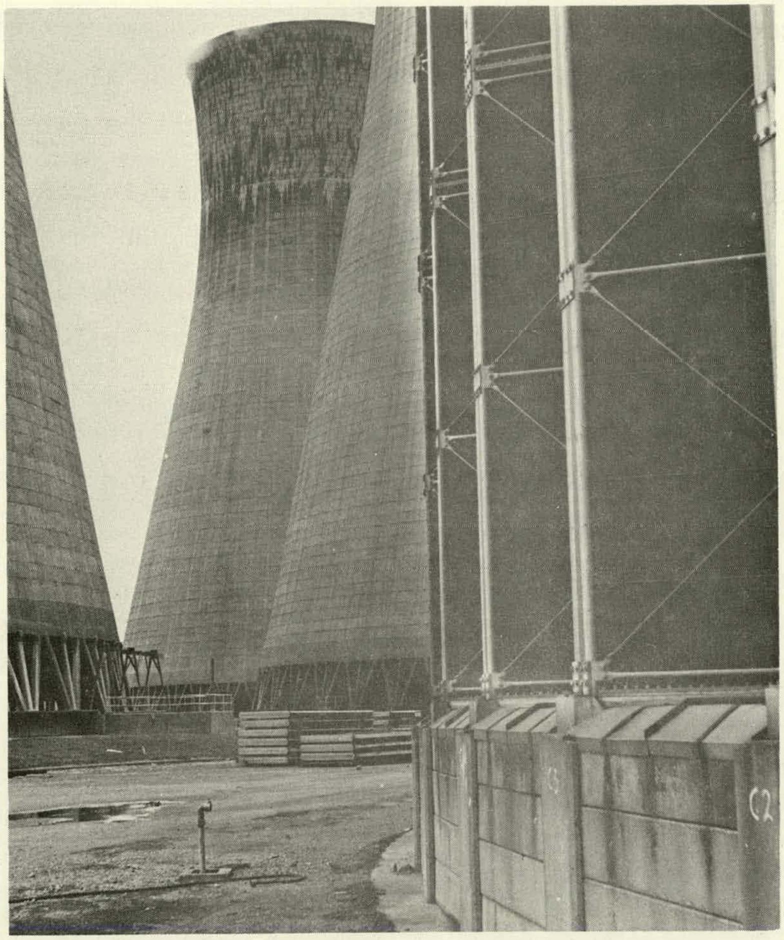


FIGURE 5.1-2. Proximity of Dry Cooling and Evaporative Towers at Rugeley

In the dip-coating process, the surface tension of the liquid epoxy created a concave meniscus between star points which reduced the coating thickness periodically around the tubes in phase with the star point pattern. Two dips producing a 2-mil coating were specified to provide the required corrosion protection on fins and tubes. The meniscus region was typically tenths of mils at its center and tended to be porous. The overall effect of the meniscus was to concentrate corrosion cells directly on the tube wall between the star point spacers.

During this visit, numerous leaks were observed in operating sections of the heat exchanger, evidence of the meniscus effect. The problem is being effectively controlled, however, by recoating the outward facing surfaces to increase the thickness of the protective epoxy and by simple injection techniques of an epoxy cement to seal leaks within the tube matrix.

The cost of gaining this experience has been relatively high compared with the cost of the original heat exchanger (£648,000 in 1960). The cost of corrosion research and retubing was estimated to exceed £1,000,000. During the course of this experience, a policy was adopted of replacing deltas on a rotational basis when leaking became excessive. A replacement delta is shown in Figure 5.1-3 on a dolly inside the tower. More recently, the injection of epoxy has been developed as a very low cost solution involving no dismantling or sector downtime.

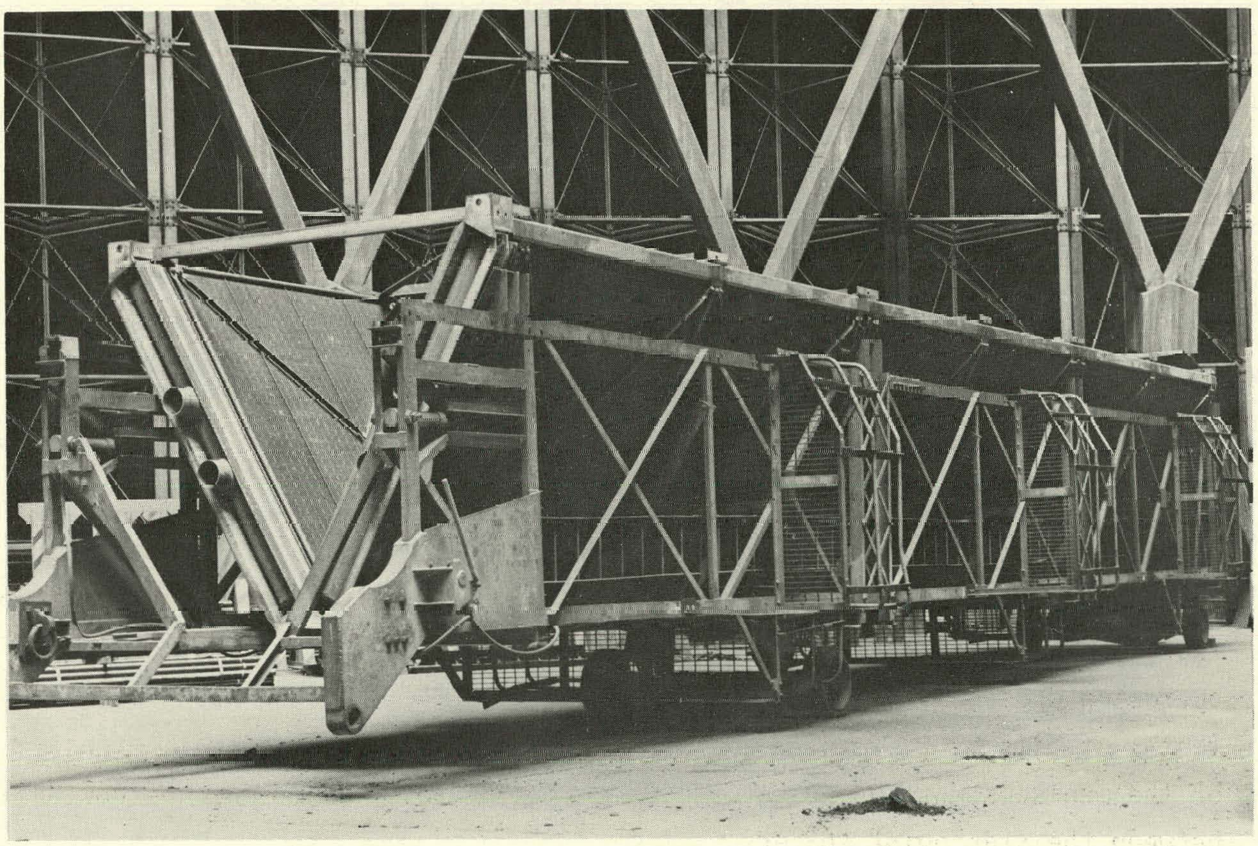


FIGURE 5.1-3. Replacement Delta, Rugeley Power Station

5.1.4 Water-Side Chemistry

No water-side corrosion has been observed in the cooling system. A recent assay of a cooling water sample from the tower circuit was supplied during the visit with the following composition:

Al	- 0.035 mg/ℓ
Fe	- 0.015 mg/ℓ
Cu	- 0.003 mg/ℓ
Ni	- 0.001 mg/ℓ
Morpholine	- 0.1 mg/ℓ
O_2	- 0.06 mg/ℓ
CO_2	- 0.04 mg/ℓ
Conductivity	- 1.5 to 2 μmho/cm
pH	- 8.8

Morpholine is added at a rate of 0.25 liter/day to the feedwater to control pH. The above values for both aluminum and oxygen have risen significantly in comparison with Rossie's values of 0.02 mg/ℓ.[1] Soluble iron has remained essentially constant since Rossie's visit. The quality of the circulating water is checked by routine weekly sampling and analysis.

5.1.5 Freezing Experience

Freezing experience has not worsened since Rossie's report.[1] Freezing problems are avoided principally by the routine discipline of attempting to limit the temperature of the cooling water leaving the tower to a minimum of 11°C. When this temperature falls to 7°C, rapid draining of one or more sectors is initiated. The vertical tubing permits draining or filling in about two minutes. The draining expedient is essentially an emergency procedure and the approach to protection against freezing is normally handled by valving off sectors and full capacity operation.

Experience at Rugeley includes only a few instances of tube rupture as a result of freezing (six events in six years) and a once or twice per winter need to reduce power (approximately 25 percent reduction) to avoid the potential onset of freezing. In retrospect, the dry cooling tower at Rugeley should have been fitted with louvers, which, in the relatively moderate climate of England, would have been a totally adequate method of preventing the problem.

5.1.6 Maintenance Frequency and Cost

The overwhelming maintenance problem until recently has been the need for retubing caused by corrosion penetration in the tubes of the heat exchanger. Retubing when necessary was accomplished on a continuous basis without plant shutdown by valving off the sector under repair. Corrosion repair has been budgeted at about £100,000 per year and involved three to four men continuously. The total unanticipated cost to date for retubing and corrosion damage repair has been £700,000. Approximately four man-months per year are necessary to maintain the balance of the cooling system. General plantwide maintenance is accomplished at 27-month intervals when a routine 11-week plant shutdown is scheduled to permit a mandatory boiler inspection.

5.1.7 Fouling

The sintering plant for PFA aggregate is upwind and in the immediate vicinity of the dry tower. Dirt from the plant blows directly into the heat exchanger causing fouling to the extent that heat rejection capacity is reduced. A ring of water hydrants has been built around the tower and washing of the outer accessible tubes keeps the tendency to foul under control. Two men are required for a week once per month to wash the entire perimeter of the heat exchanger. Water cost of £0.13 per 1000 gallons is an essentially negligible additional cost.

5.1.8 Atmospheric Effects

Atmospheric effects were covered adequately by Rossie[1] and subsequent experience has been of the same general nature as he discussed. A noticeable disturbance of the natural draft has been observed in heavy rain. Also, draft is sometimes affected by operation with one quadrant out of service. The prevailing winds carry pollutants which, as described above, contribute corrosion and a tendency for fouling.

5.1.9 Cooling Tower Effect on Plant Availability

The cooling tower performance has a negligible impact on plant availability. Corrosion, although it has been the pacing item, is handled on a sector-by-sector basis. Repairs can usually be accomplished without reduction in the desired output of the plant.

5.1.10 Environmental Impact and Siting

The environment in the case of Rugeley appears to have more impact on the dry cooling system than vice versa. Very few complaints have been received from inhabitants of the area about Rugeley Plant operation. In the last two years, only one complaint was received and this related to the aesthetics of plumes from the evaporative towers.

In the past, plant noise from fans, alarms, and motors has been objectionable; however, silencers were added to the blowdown system, which appeared to be the principal source.

The potential for further improvement involves the addition of precipitators to clean up stack emissions. This is not planned because of the expense and extent of rebuilding required.

The environmental effects of industrial plants in Rugeley appear to enjoy a high level of public tolerance motivated by self-interest in protecting opportunities for continued employment. The environmental impact of the power plant complex was reviewed at a public inquiry prior to construction. Adequate climatological data were available at that time to permit the evaluation of site suitability and environmental impact according to standards then in existence. If a similar plant were to be built today, the stack height would be increased to 600 feet from the present 450 feet, to improve dissipation of stack gases and emissions. With the present stack height, interference with the plumes from the evaporative towers is noticed.

5.1.11 Concluding Remarks

The experience at Rugeley has added greatly to the world's knowledge concerning operation of large-capacity air-cooled heat exchangers. The combination of circumstances contributing to the corrosion problem are understood and totally avoidable with current technology and site selection. As a full-scale experimental facility, the Rugeley dry cooling system has isolated causes of a major potential problem, which otherwise could have remained unrecognized or could have afflicted a non-experimental installation.

5.2 DRY COOLING EQUIPMENT AT THE VOLKSWAGENWERK AG POWER PLANT, WOLFSBURG, GERMANY

Date of Visit: April 1, 1975

Participants in the Discussion:

Mr. F. Wehrberger, Chief of Energy Production
Mr. R. D. Dürr, Power Plant Manager
Mr. E. Kirchhübel, Maintenance Supervisor
DeSteese - PNL
Simhan - BF

5.2.1 General Remarks

The Wolfsburg power plant operated by Volkwagenwerk AG has the highest capacity in Europe equipped with GEA air-cooled direct condensing systems. Four 48-MWe units (Units A, B, C, and D) were installed sequentially in 1961, 1962, 1966, and 1972. The power plant supplies power and steam heating for automotive manufacturing processes as well as power and district heating for the town of Wolfsburg. The district heating load is largest in the winter and, as a result, the plant heat rejection system is loaded most heavily in the summer.

The rationale for installing dry cooling towers was based on a detailed economic comparison of evaporative and dry systems. A deciding factor was the availability, cost, and logistic disadvantages of providing water for evaporative cooling. Overall operating experience with the GEA dry cooling systems has been highly satisfactory and has thoroughly demonstrated the reliability of galvanized steel heat exchangers under cyclic service conditions. Volkswagenwerk management plans to increase the size of the power plant following the modular addition policy of the past, as power and heating requirements increase. An additional 80 to 100 MWe is anticipated to be needed in the early 1980s. The Volkswagenwerk power plant is discussed in References 1, 2, 5, 7, 8, and 9. Rossie's review[1] of operating experience is valid today regarding Units A, B, and C. Unit D was added since Rossie's field trip. Mr. Wehrberger courteously provided a sample of GEA plate-finned, elliptical tubing taken from Unit B after seven years' operation. Analysis of this sample is discussed in Reference 6.

5.2.2 General Operational Data

The Volkswagenwerk power plant is equipped with controlled extraction-type turbines which provide steam for process or district heating at constant pressure. The power plant was constructed in two sections. The first, and older, section is evaporatively-cooled. The performance of units in the old section was generally satisfactory; however, the cooling tower plumes were susceptible to recirculation. The plumes also created high humidity conditions in some buildings of the manufacturing plant according to seasonal weather conditions.

A new power plant section was planned in 1960 to accommodate increasing demand for heat and power. At this time, a trade-off study was made to decide whether evaporative or dry cooling should be selected for the new plant section. An economic comparison showed that direct condensing dry cooling systems would cost less than the placement of wet towers at least 3000 feet away from the power plant. This distance was considered necessary to eliminate recirculation and humidity problems experienced with evaporative systems in the old power plant section.

The new power plant section contains four units rated at 40 MWe and 48 MWe under summer and winter conditions, respectively. Throttle steam conditions are 977°F and 1616 psi. At the maximum rating, the design turbine back pressure is 3.3 inches Hg with 59°F ambient. The corresponding ITD between saturated steam in the condenser and ambient temperature is 51°F.

Each turbine-generator unit is connected to its own block of four air-cooled condenser modules mounted on the roof of the turbine building. The modules contain various arrangements of standard and counterflow condenser sections.[1,7-9] The sections are constructed from GEA hot-dip galvanized, elliptical steel tubing and steel plate fins. Draft is provided by two-speed fans arranged three fans per module, with a total of 12 fans per turbine unit.

On an elapsed-time basis the sequential installation of Units A through D contributes a total of 39 unit-years operation. With rated condensate flow rate of 242,000 lb/hr, the condenser heat load will be 2.49 x 10^8 Btu/hr per unit. The corresponding merit index would be approximately 9700. However, the plant generally has excess capacity over demand throughout the year and units are run as spinning reserve or are shut down completely as conditions vary. Using data from Reference 9, unit downtime appears to range typically between 25 percent and 35 percent. When this downtime is accounted for as an average of 30 percent, the merit index is about 6800. This value is still one of the largest in Europe and increases in significance because of the cyclic nature of unit operation. Units which are shut down over weekends and holidays are allowed to fill with atmospheric air.(9) This duty is more stringent than that which would be typical of U.S. utility operation and therefore emphasizes the reliability of the GEA system with respect to corrosion resistance and condensate quality control.

5.2.3 Corrosion Experience

The air-cooled condensers at Wolfsburg have been totally free from both air-side and condensate-side corrosion during their operational histories. Rust occurred on the insides of finned-tube bundles of Units A and B as a result of hydraulic pressure testing during manufacture. A phosphoric acid treatment was employed to remove the rust and protect the tube interiors with a phosphate layer. This was also desirable as a method of removing mill and welding scale which otherwise is transported around the system in the condensate.

Under normal duty conditions the phosphate would have been removed by ammonia addition to the turbine exhaust. As a result of low load conditions, this was not totally effective and phosphate was transported to the boiler. However, this material was drained off and no damage to the system resulted.

The pressure test of tube bundles for Unit C was performed under water with compressed air. This procedure avoided the rust problem and the need for phosphate treatment. Filters were installed upstream of the condensate pump to trap transported scale. The filters required frequent cleaning during the first year of operation; however, after one year, scale collection reduced to zero and the filters were removed. A return to phosphoric acid treatment was decided for the tube bundles of Unit D.

Some erosion of the zinc coating on the air-side leading edge of fins has been determined. A typical fin is coated with zinc by the hot-dip galvanizing process to a thickness in the range 24 to 48 μm. Units A, B, and C have enough exposure to exhibit measurable erosion of the zinc coating commensurate with their service life. Linear extrapolation of the erosion observed to date suggests the galvanizing will be good for the balance of approximately 50 years' protection in the rural environment of Wolfsburg.

5.2.4 Condensate Quality

No in-service corrosion has been apparent on the condensate side of the system. Condensate quality at Wolfsburg is held to the following limits:

O_2	- 0.01 mg/ℓ
Fe	- <0.02 mg/ℓ
Cu	- 0.005 mg/ℓ
pH	- 9 to 9.3
Conductivity	- 5 to 7 μmho/cm

Hydrazine is added in the range 30 to 40 μg/ℓ to control oxygen. Ammonia is the only other condensate additive. A large transient increase in oxygen and iron content occurs during startup;[8] however, the use of air ejectors reduces this to normal levels within a few hours.

5.2.5 Freezing Experience

Freezing has occurred on two occasions in the winters of 1964/65 and 1965/66.[9] In the first case, four condenser tubes of Unit A were found to be cracked and were removed. The holes in the condenser were plugged and welded. The second case of freezing happened the following winter in Units A and B, resulting in the removal of one tube from each condenser. The severity of these cases was associated with colder than usual winter temperatures and condensate flow rates below the range for which fan speed control can be used to reduce the rate of heat transfer.

As Rossie discussed in detail,[1] freezing problems are avoided by operational procedures (as practiced at Rugeley) including maintenance of a minimum condensate temperature (41°F) when ambient reaches 32°F. Also involved in the control procedures are requirements for condensate flow rate and fan speed.

The incorporation of Dephlegmator (counterflow condenser) sections is a component of the freeze protection design philosophy in the GEA system. The counterflow coils exhibit a lower heat transfer coefficient than that of the standard condenser. In Units A and B, one of the four condenser sections contains only counterflow elements. The condensers of Units C and D have standard and counterflow elements in each section. It appears that the optimum number and distribution of counterflow elements is still a subject of in situ research at the plant.

5.2.6 Maintenance Frequency and Cost

Maintenance and repair costs[8] of the air-cooled systems average 0.7 percent of the annual maintenance cost for the power station as a whole. In 1974 the dry cooling systems of Units A through D cost about DM 44,000 to maintain. The principal components requiring routine attention are gears, motors, condensate pumps, air ejectors and fittings. Lubrication of gearing on the fan motors gave a little trouble in the early days of operation. This problem was solved by selection of all-weather lubricating oil.

An annual requirement of between 70 and 100 man-hours/yr are required per unit to clean dirt off the condenser fins. After trying compressed air without total success, pressurized water[9] at 70 psig is used in this routine. The condensers, fan motors and lubricating systems are inspected each shift,[1,8] which requires an additional 1/4 man-hour per shift. Overall experience at Wolfsburg shows the maintenance requirement of the air-cooled equipment to be lower than that of evaporative systems in the older power plant section.

5.2.7 Fouling

The local, basically rural, environment contributes very little pollution or material which can foul the condensers. A coating of dust and dirt from various sources accumulates slowly throughout the year. The predominant weather direction-side of the condensers tends to be kept clean by the rain. Annual cleaning with pressurized water prevents any serious long-term buildup; no loss of heat rejection capability has ever been observed as a result.

Plant management has been concerned by workers who bend or damage fins by careless placement of ladders and tools while working around the condensers. While this has not impaired operation of the equipment, it appears to be the most noticeable cause of any damage which has occurred. In contrast, the robustness of the steel finned-tube assemblies is completely resistant to stresses imposed by the pressurized water cleaning procedure.

5.2.8 Atmospheric Effects

The overall influence of atmospheric effects is minimized by the use of forced draft. Wind effects have been noted, however, which in the worst cases, reduce heat rejection of some condenser modules as much as 25 percent. This situation is associated with winds blowing from the east placing the condensers in a partial wind shadow of the boiler house (Figure 5.2-1). The boiler house apparently sheds eddies contributing to unequal air distribution across the condensers and local recirculation. The reduction in heat rejection capability does not have a large impact on ability to supply the demand load on the system. Plant operational policy provides ample reserve margin to absorb such effects.

An enhancement of heat rejection capability is interpreted from vacuum improvements of between 0.2 and 0.9 percent during light uniform rain. Heavy rain is similarly helpful when operation at peak output is required.

5.2.9 Cooling Tower Effect on Plant Availability

The performance and operational condition of the dry cooling system has never affected plant availability. Operating policy, however, permits a very flexible response to emergencies, including the ability to partially interrupt the supply of power and process heat to the manufacturing plant

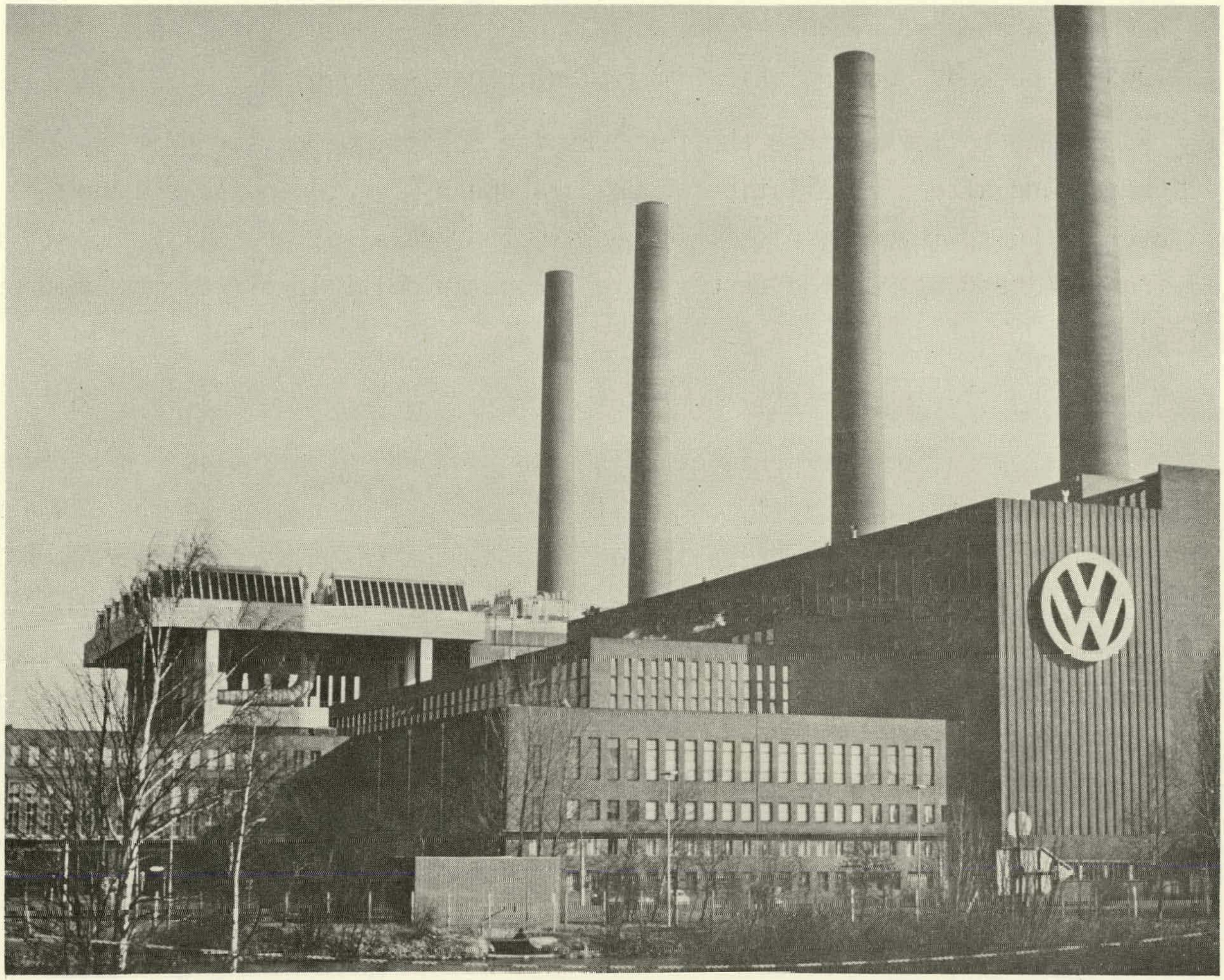


FIGURE 5.2-1. View of Volkswagenwerk AG Plant from South Showing Deltas on Leeward Side of Boilerhouse when Wind Blows from the East

to accommodate the power demands of the town. Most of the time operation of the power plant is based on a high degree of redundancy in terms of shut-down units or spinning reserve.

5.2.10 Environmental Impact and Siting

The dry cooling system has a negligible impact in excess of the environmental effect of the plant as a whole. As in Rugeley, some industrial pollution is tolerated by the local population because the industries are major local sources of employment. Fly ash and SO_2 emissions from the power plant have been reduced by 35 percent and 30 percent, respectively, in the 1963-73 period. During this time, plant capacity doubled.

Noise pollution from the fans was the subject of research at the plant before and after installation of Units A and B.[8] Fan noise causes the overall noise level to rise from 66dB(A) to 77dB(A) at approximately 160 feet from the condensers. No perceptible change in noise level was measured outside the plant site, as a result of operating the dry cooling systems.

5.2.11 Concluding Remarks

The operational experience at the Volkswagenwerk plant is impressive evidence of the reliability and resistance to deterioration of the GEA direct condensing system. The installation also demonstrates performance according to, or slightly better than, design specifications. The frequent cyclic shutdown/restart mode of operation is potentially a more severe test of condenser resistance to internal corrosion than would be expected from conditions associated with base load operation. An important endorsement of satisfactory performance is that Volkswagenwerk AG has been a four-time repeat customer for the GEA system and future enlargement of the plant is anticipated using similar modules.

5.3 DRY COOLING EQUIPMENT AT THE PREUSSAG AG POWER PLANT, IBBENBÜREN, GERMANY

Date of Visit: April 2, 1975

Participants in the Discussion:

Mr. R. Holler, Branch Manager, Energy Operation

Mr. H. Krahnert, Plant Manager

Mr. H. Aschendorf, Laboratory Manager

DeSteese - PNL

Simhan - BF

5.3.1 General Remarks

The Preussag AG dry cooling tower at Ibbenbüren[1,10-12] is another example (after Rugeley) of the intrinsically reliable Heller-Forgó system operating less effectively than planned because of an adverse environment. The location of the dry cooling tower in the vicinity of wet cooling towers and downwind of a pulverized coal storage area has caused fouling of the heat exchanger. Coal dust and fly ash bound by moisture to form a cake-like coating has proven difficult to remove. As a result, plant management, although taking advantage of an initial 10 percent overdesign performance margin as partial compensation, is tolerating an effectivley permanent reduction in heat rejection capability.

The dry cooling system at Ibbenbüren was selected for a 150-MWe unit addition to the existing evaporative-cooled plant. The old plant contains three turbine-generators with a combined capacity of 92 MWe. The cooling water requirement for the two evaporative towers of the old plant amounted to half the capacity of the water supply at this site. Economic analysis showed that a dry cooling system would be preferable if water cost exceeded approximately $0.35/1000 gallons.[1] The actual cost of water from Preussag's own water-treatment plant was $0.47/1000 gallons and would have risen to $0.65/1000 gallons if a new supply had been developed for a third evaporative system. The extensive economic study also included a review of other types of cooling systems, from which the Heller system was chosen.

Other than the fouling problem, overall experience with the dry cooling system at Ibbenbüren has been satisfactory. The plant management feels that the fouling was exaggerated by three months of downtime in 1970 caused by turbine problems. If routine cleaning had been practiced from the time of commissioning and during downtime, the Forgó heat exchanger could be expected to stay free of fouling material in the Ibbenbüren environment. Management confidence in the system is indicated by plans for expansion of the power plant with similar units. A plan for the addition of 680 MWe capacity is scheduled for review in late 1975 or early 1976.

The Preussag AG Heller system has been described in several publications.[1,10-12] Rossie's report of a field trip to the plant in 1969 is an especially useful English language reference.[1] As with the treatment of Rugeley and Wolfsburg, this discussion is intended as a supplementary updating of Rossie's review. A sample of Forgó finned tubing was kindly supplied representing seven years' use between 1967 and 1974. A metallographic analysis of the sample is reported in Reference 6.

5.3.2 General Operating Data

The dry cooling system at Ibbenbüren possesses many elements of similarity to the Rugeley tower and some important differences. Both systems employ natural draft generated by a reinforced-concrete hyperbolic tower. The Ibbenbüren turbine generator is rated at 150 MWe with throttle steam at 976°F and 2719 psi, and a 976°F reheat at 500 psi.

At rated power the heat rejection load is 6.45 x 10^8 Btu/hr. The design turbine back pressure is 1.22 inches Hg with a 35°F ambient air temperature. The corresponding ITD is 50.5°F, which contrasts with the 35°F ITD of Rugeley with a 52°F ambient. As a result, the Ibbenbüren plant needs only 498 cooling elements compared with 648 at Rugeley. Other points of contrast between the two installations are:

- the design of the direct contact condenser;
- the use of louvers for freeze protection at Ibbenbüren;
- independently controlled valves at Ibbenbüren for isolating, filling and draining the four cooling tower sectors.

The operational merit index for Ibbenbüren has a nominal value of 5160. If downtime and reduced capability are considered, this value is reduced by approximately 25 percent to 3900, which ranks Ibbenbüren next below Rugeley and in fourth place for Heller systems.

5.3.3 Air-Side Corrosion Experience

The heavy deposits of fouling material contain chlorides carried in the drift from adjacent evaporative towers, fly ash from the stack and dirt thrown up by passing vehicles.[12] Electrolytic action involving Cl^- and $SO_4^{=}$ ions has resulted in noticeable local corrosion on the leading edges of the aluminum fins. The components of the cooling elements were treated by MBV (Modified Bauer Vogel) method which results in a 1- to 2-μm thick protective layer of aluminum-chrome oxide.[12] Grease was applied between tubes, spacers and fins which served the dual purpose of aiding assembly and sealing joints. As a result, corrosion at Ibbenbüren has been essentially trivial compared to that at Rugeley, although the corrosion processes are similar at both locations.

Corrosion has not touched the spacing elements or the tubes in the Ibbenbüren heat exchanger. Management is confident at this time that corrosion of the presently-observed nature does not threaten a reduction in the design life expectancy of the heat exchanger.

5.3.4 Water-Side Chemistry

No water-side corrosion has been observed. Hydrazine is added at the rate of 0.05 mg/ℓ to the feed water to maintain the pH range of 7.8 to 8. The aluminum solubility measured in a period of 45,000 operating hours, if considered to be uniformly removed from the tube interiors, corresponds to a reduction in tube thickness of 4.6 μm.[12] The dissolved aluminum from the heat exchanger has not shown any effects in the boiler or turbine.

Oxygen content in the cooling water is in the range 10 to 300 μg/ℓ depending on power output. Iron up to 10 μg/ℓ and aluminum less than 20 μg/ℓ are observed in cooling water samples taken routinely once a day. Boiler feed water is filtered through asbestos-coated screens and is demineralized,[1] which further reduces aluminum content to less than 2 μg/ℓ. Conductivities less than 0.3 μmho/cm are observed.

5.3.5 Freezing Experience

A single occurrence of freezing was caused by the failure of a valve used to drain a section of the heat exchanger. Freezing protection[1] is achieved routinely over a power output range from 30 to 150 MWe, by lower operation, deactivating a cooling water circulation pump, draining heat exchanger sectors and use of a bypass in the circulation system.

5.3.6 Maintenance Frequency

Maintenance of the cooling system is generally performed during plant shutdown periods. Management policy is to hire an outside contractor to handle maintenance problems. No replacement of tube sections in the heat exchanger has been required. Current experience shows water-side dissolution of aluminum to be the pacing item and the presently-observed rate indicates a tube life of approximately 25 years. A seal life of between three and five years in water-circuit couplings and fittings has been indicated. Seals are replaced as necessary when small leaks occur.

5.3.7 Fouling

Air-side fouling, as indicated previously,[12] is the only element of negative experience at Ibbenbüren. A management estimate is that approximately DM 50,000 may be needed to clean up the heat exchanger using compressed air, water and chemical treatments. However, experiments on a demounted tube section showed there is little hope of finding a method of cleaning which will remove the strongly adhering deposits without disturbing the protecting grease layer. Compressed air was found effective in removing loosely attached deposits and some of the more tightly bound layer. Pressurized water, steam and alkali solvents were also tried. Water at high pressure tends to damage the soft aluminum fins. In this respect, the robustness of galvanized steel finned-tube bundles is an advantage.

A management attitude at Ibbenbüren is that the problem would never have occurred without the three-month downtime in 1970. It is felt that the heavy deposits formed in the absence of the normal operating draft. Under operating conditions, the major portion of airborne dirt would remain airborne during its passage through the finned tube assembly.

The extent of the present problem has not been fully evaluated. Draft measurements indicate a reduced heat rejection capability; however, the turbine has been operating for years without two expansion stages and the tower has an intrinsic 10 percent overdesign heat load capability. With the load factor of the turbine and all other conditions combined, the cooling tower has performed adequately ever since fouling material accumulated. Management has a high degree of confidence in the Heller-Forgo system and feels routine compressed air cleaning would have prevented the problem entirely.

5.3.8 Atmospheric Effects

Wind velocity-dependent effects decrease the performance of the cooling tower. The cooling tower at Ibbenbüren appears to be somewhat more sensitive to wind velocity than that at Rugeley. The wind effect was underestimated in the design of the tower. Measurements conducted by the Technischen Überwachungs-Verein (TÜV) indicate typically a rise in cooling tower temperature of 5.4°F with winds of 9 mph. Heavy rain and fog are also detrimental and cause a reduction in natural draft as a result of cooling the air mass rising in the tower.

5.3.9 Cooling Tower Effect on Plant Availability

The plant has demonstrated an availability in the range of 88 to 92 percent. Availability is controlled mostly by the condition of the boiler. The cooling system has never influenced the availability of the plant as a whole. The fouling problem may restrict operation at maximum rated power, when the turbine is restored to its original capability. However, the 10 percent excess capacity in the heat rejection design capability may prove to be adequate compensation.

5.3.10 Environmental Impact, Siting, Codes and Standards

The only environmental impact chargeable to the power plant is the occasional formation of ice on roads caused by the plumes of the evaporative towers. No complaints have been received about operation of the dry tower or cooling system.

As the Preussag AG plant is in a coal mine district, siting and construction are under the jurisdiction of the state mining authorities. The design of the dry cooling tower reflects concern for the subsidence tendencies in this undermined area. As a result, factors of safety seven times normal were applied to elements of the structural design.

5.3.11 Concluding Remarks

The performance of the dry cooling system at Ibbenbüren appears to match the current derated capabilities of the turbine-generator unit. A heat rejection margin 10 percent in excess of the design capability may prove adequate compensation for the capability lost by fouling, if the turbine is restored to its original rating. The dry cooling system is considered by the plant management to be a successful implementation of the Heller-Forgó system and future unit additions of this type are favored.

5.4 DRY COOLING EQUIPMENT AT THE UNION TERMICA S. A. POWER PLANT IN UTRILLAS, SPAIN

Date of Visit: April 11, 1975

Participants in the Discussion:

Mr. Ranon Sanchez Alegre, Power Plant Director

Mr. Manuel Espejo

Mr. Bajilo Barzo

Mr. Francisco Perdigones Belenguer, Chief, GEA Technical Office in Madrid

Mr. Carlos Fernandez Fanjul, GEA Technical Office in Madrid

DeSteese - PNL

5.4.1 General Remarks

Whereas the Volkswagenwerk AG power plant has the largest total capacity (4 x 48 MWe) cooled by the GEA direct condensing system, the Utrillas plant contains the world's largest single turbine generator unit (160 MWe) equipped with the GEA system. The Utrillas plant has several characteristics which correlate with operation under conditions to be found in the U. S. The size of the single unit cooling system and operation as a minemouth, base-loaded and utility-integrated power station are within ranges of reasonable extrapolation to U.S. requirements. Similarities to U.S. conditions also include siting rationale and climate.

The UTSA plant embodies 30 years' development experience and experimentation with smaller units operating under diverse conditions. With over five unit-years of operating experience, the Utrillas plant should rank as an important focus of interest for U.S. utility operators.

Planning, construction, and operational experience of the Utrillas plant are reported in the literature.[5,9,13,14] This subsection includes updating information supplementing the review of operating experience contained in Reference 14.

5.4.2 General Operating Data

The Union Termica S. A. (UTSA) of Barcelona built and operates the 160 MWe Utrillas power plant. The mine-mouth plant site is in the Spanish Province of Teruel approximately six miles south of Montalbán. Siting was decided by economic comparison of the cost of transporting fuel to an area with sufficient water for evaporative cooling, versus the incremental cost chargeable to dry cooling required at the mine-mouth site as a result of water scarcity. Lignite fuel for the plant is transported by conveyor directly from a storage area adjacent to a mine operated by Minas y Ferrocarril de Utrillas S. A. (MFU). Table 5.4-1 compares some significant statistics of the 160 MWe Utrillas and the 330 MWe plant under construction at Wyodak.

Because of similarities in design and operation, the Utrillas plant represents an opportunity for U.S. utility personnel to preview several aspects of operation at Wyodak, at approximately half-scale.

The condenser system of the Utrillas plant consists of eight Δ-shaped rows each containing five condenser sections.[13]

TABLE 5.4-1. Comparison of Power Plant Characteristics

	Utrillas	Wyodak
Nominal Rating (MW)	146/160	330
Location: Site	Mine Mouth	Mine Mouth
Elevation (ft)	3280	4410
Ambient Temperature Range (°F)	-4 to 103	-40 to 100
Steam Conditions:		
Temperature (°F)	980/980	1000/1000
Pressure (psi)	2560	1800
Condenser Load (Btu/hr)	6.68×10^8	1.87×10^9
Turbine back pressure (inches Hg)	2.9/3.4	6
at ambient temperature (°F)	59	66
Initial Temperature Difference (°F)	54	75

Two sections at each end of the row are connected as standard condenser elements. The center section is arranged as a counterflow (Dephlegmator) condenser.[13,14] Forced draft is provided by 40 fans arranged five to a row. Condenser elements contain a staggered array of standard GEA elliptical finned-tubes, hot-dip galvanized for a zinc coating thickness of 60 μm. The entire system is built on a platform supported by a steel structure above the turbine building.

The nominal merit index for the Utrillas plant is approximately 3340. This ranks third behind Pietrafitta and Wolfsburg and seventh when all European direct condensing and Heller systems are considered.

5.4.3 Corrosion Experience

The condenser system at Utrillas has been entirely free from both air-side and water-side corrosion.

5.4.4 Condensate Quality

Condensate quality is determined by routine analysis once a day. Condensate is held to the following limits:

O_2	-	0.01 mg/ℓ
Fe	-	<0.02 mg/ℓ
pH	-	8.5 to 9
Conductivity	-	0.2 μmho/cm

Hydrazine is added at the rate of 0.02 mg/ℓ. The plant is supplied by spring water[13] piped 5.6 miles to a water treatment station and a 1000 m^3 storage tank located to the north of the plant. Demineralized water is supplied to the plant.

5.4.5 Freezing Experience

No experience of freezing has occurred in over five years' operation.

5.4.6 Maintenance Frequency and Cost

The cooling system at Utrillas requires about 500 man-hours per year for routine maintenance. This includes cleaning the condenser with compressed air and lubricating the gears and bearings of the fan motors.

5.4.7 Fouling

Winds from the south carry coal dust from the storage site and deposit a light dust on the finned-tube bundles. Once-a-year cleaning with compressed air removes any accumulation. The manpower cost is considered routine maintenance and is part of the above 500 man-hour estimate. Efficient precipitation prevents fly ash from the stack being blown into the condenser elements. No deterioration of heat rejection capability has ever been noticed as a result of the light coal dust coating on the heat exchanger.

5.4.8 Atmospheric Effects

The siting and plant configuration were planned using models to predetermine wind effects.[14] The modeling technique also explored arrangements which would allow for future addition of two more 160-MWe units. As a result, the optimum height and location of the condenser platform was determined with respect to the configuration of the plant as a whole. This careful design procedure has contributed to the absence of recirculation and wind effects.

5.4.9 Cooling Tower Effect on Plant Availability

The Utrillas plant supplies power to the Spanish national power grid with an average availability of 7000 hours/yr. The plant is shut down for a 30-day period once a year for inspection and maintenance. The cooling system as a whole has never influenced plant availability.

Once in five years, a two-hour reduction in output was necessary to prevent the upper (7.5 in. Hg) turbine back pressure operational limit from being exceeded while operating with a 93°F ambient air temperature. The condenser is designed to permit the generation of 160 MWe with 7.5 in. Hg turbine back pressure in an 86°F ambient. Operation in up to 93°F ambient air illustrates the margin in excess of guaranteed performance which the cooling system possesses.

5.4.10 Component Failure

Experience at Utrillas includes a small number of component failures which are mostly in the categories of startup or random problems. Over a five-year period, failures involving a transformer, three motors and a fan blade breakage have occurred. By coincidence, the fan blade breakage was a recent event and was awaiting repair at the time of this plant interview (Figure 5.4-1). After 1 1/2 years operation, two fan drive gear assemblies required attention as a result of inadequate lubrication. All of these occurrences are relatively trivial and were accommodated without disturbance to normal plant operation.

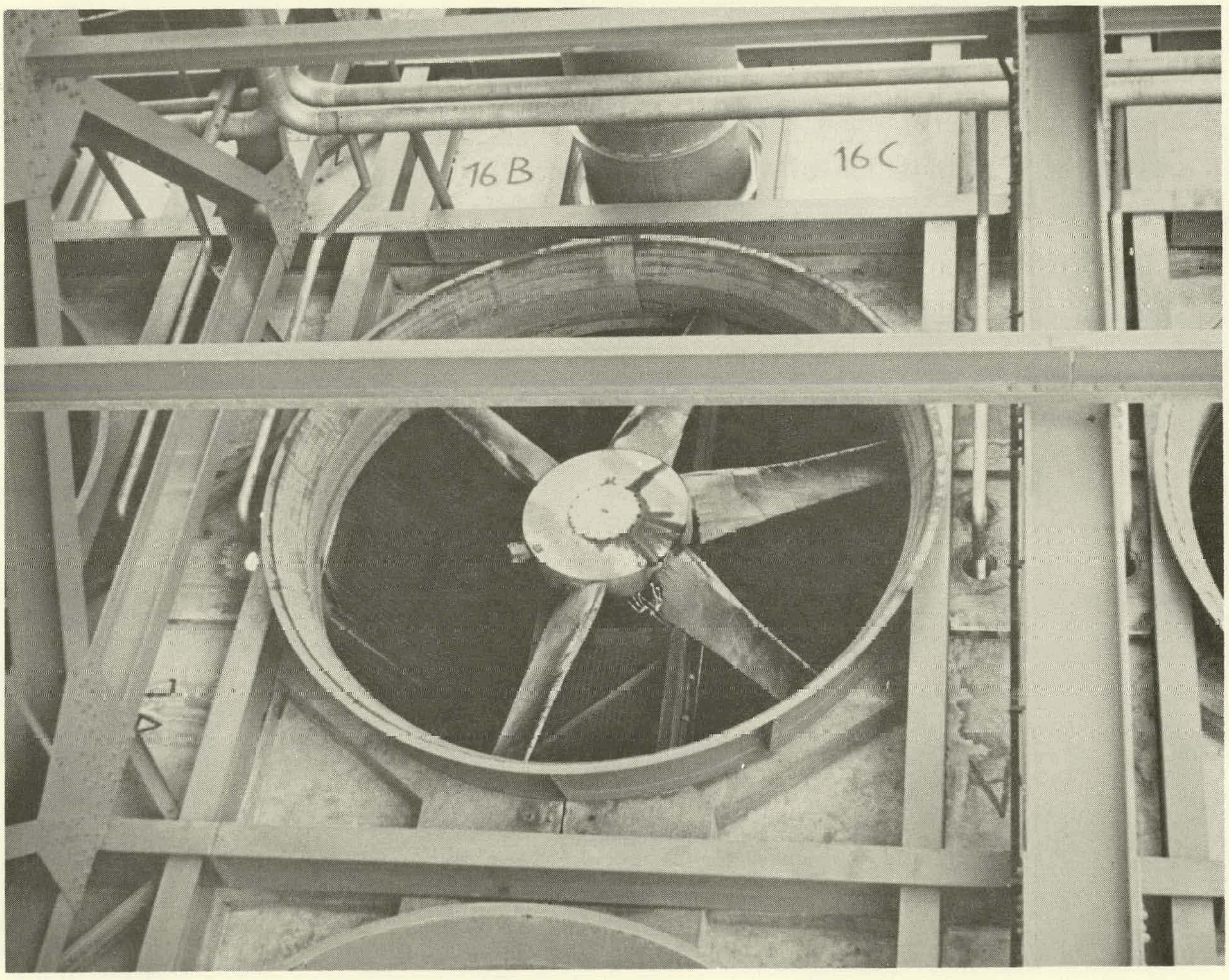


FIGURE 5.4-1. Fan Blade Breakage, Union Termica S.A. Power Plant

5.4.11 Environmental Impact, Siting, Codes and Standards

No complaints have been received about siting or operation of the plant. Emission control devices limit stack emissions and climatological data were available and were used in the plant design phase. Codes and standards were followed during both construction and operation of the plant. The standards of the AD Merkblätter (ASME type) and regulations of the Reglamento de Recipientes a Presion (Spanish Ministry of Industry) were applicable.

5.4.12 Concluding Remarks

The UTSA power plant at Utrillas demonstrates the reliability of a direct condensing cooling system applied to a large turbine-generator unit. The cooling system and plant as a whole have shown essentially trouble-free, as-designed performance for over five years. All evidence at this time suggests the continuation of this experience for the design life of the equipment. The success of both the Utrillas and Wolfsburg plants should inspire U.S. utility confidence in the maturity of the GEA direct condensing system and its applicability to large power plants.

5.5 EXPERIMENTAL PLASTIC TUBE AIR-COOLED HEAT EXCHANGER IN PIGNATARO MAJORI, ITALY

Date of visit: April 15, 1975

Participants in the Discussion:

Dr. Carlo Roma, Professor of Fluid Machinery, University of Rome
Dr. Vincenzo Leonelli, Project Engineer, Societa Italimpianti, Genoa
DeSteese - PNL

5.5.1 General Remarks

Dr. Roma has been a driving force for the advancement of finless plastic tube heat exchangers.[15] His research has progressed from laboratory-scale to this pilot plant demonstration sponsored by Finsider S.p.A., an effort leading to a full-scale system experimental facility.

The pilot plant has demonstrated some basic characteristics of plastic tube heat exchangers, with favorable indications of superior corrosion resistance, freeze protection and reduced maintenance. These results have encouraged Italimpianti S.p.A. (Architect Engineering Subsidiary of Finsider S.p.A) to plan a full-scale demonstration of a plastic tube dry cooling system for a 75-MWe turbine generator unit owned by the Italian National Electricity Authority (ENEL). The experiemental facility is planned for a central station site alongside conventional evaporative cooling equipment applied to other turbine-generator units. This arrangement would duplicate the type of comparative performance monitoring available at Rugeley, between evaporative and dry cooling systems.

5.5.2 General Operating Data

The pilot plant (Figure 5.5-1) is capable of rejecting 8 x 10^6Btu/hr with a 40°F ITD. The heat exchanger consists of 7200 10-mm diameter high density polyethylene (PEHD) tubes supported at intervals in a Δ-shaped structure. The tubes run horizontally (Figure 5.5-2) along faces of the 'Δ' and are sealed by grommets into coolant distribution manifolds at each end. An interesting characteristic is the irregular spacing and sagging of the tube bundles, which, although aesthetically disturbing, (perhaps only to one accustomed to the ordered arrangement of finned tubes) is claimed to

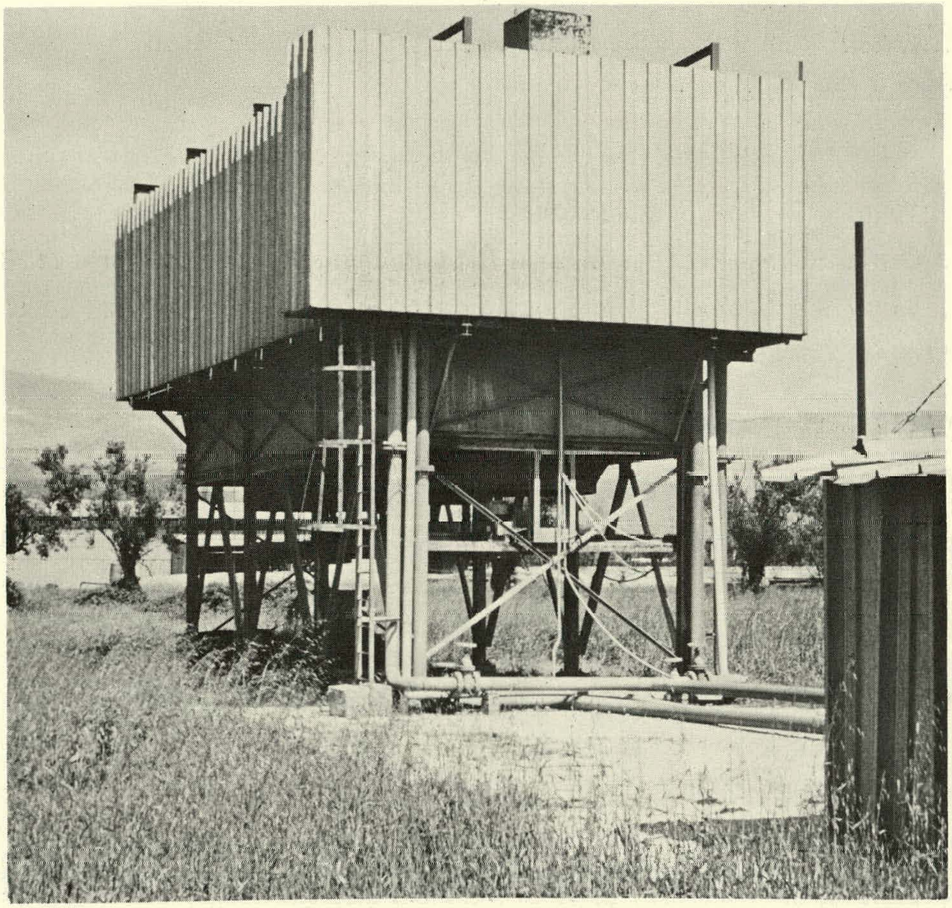


FIGURE 5.5-1. Pilot Plant for Plastic Tube Air-Cooled Heat Exchanger Experiments, Pignataro Majori, Italy

have no net effect on heat transfer. A gas-fired heater supplies the pilot plant with hot water simulating the coolant in an indirect (Heller) type system.

The heat exchanger is 38 feet long, 15 feet wide and 10 feet high. Forced draft is supplied by three variable-pitch eight-foot diameter fans mounted below the A-frame. The heat exchanger is of the cross counterflow, double-pass type. Construction of the pilot plant was sponsored by Dalmine S.p.A., a prominent European manufacturer of steel pipe and tubing and subsidiary of Finsider S.p.A.

The pilot plant was operated continuously for 10,000 hours in 1972 and 1973, and has been demonstrated occasionally thereafter for visitors.

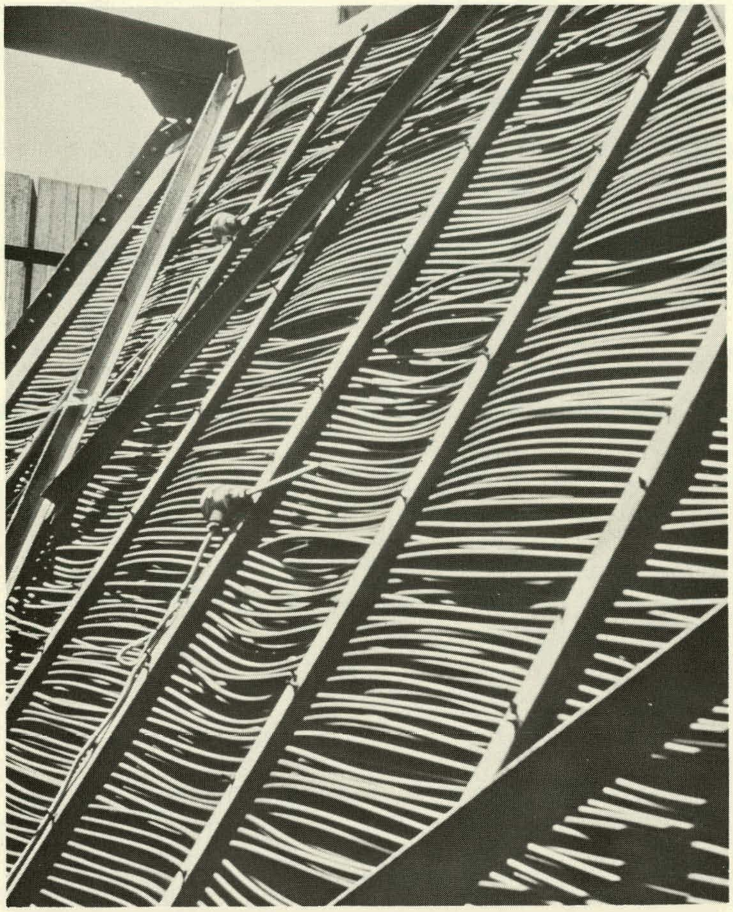


FIGURE 5.5-2. Arrangement of Plastic Tubes

Instrumented testing was complete in 1974 and further operation is not planned. The overall cost of the facility was the equivalent of $20,000 in 1972, including engineering and electrical facilities.

5.5.3 Operating Experience Summary

Operation of the test facility was generally free from adverse effects. Several plastic tubes pulled out of their grommets in the coolant manifold. This was corrected with an improved retainer device. The tendency for tubes to pull out was ended by abandoning the use of the tensioning device which was used initially in an attempt to take up the sag in the tube bundles between supports. The most satisfactory operation resulted from permitting the somewhat random sagging to absorb expansion and contraction of the tubes.

No corrosion of the air side was observed. The environment is rural with pollution carryover from industrial areas. Water-side corrosion was also absent, although no attempt was made to simulate boiler quality feed water in a full-scale power plant.

Freezing was experienced once as a result of a power failure in February 1973. A distinct superiority of the plastic-tube heat exchanger was demonstrated by this occurrence. The elasticity of the tubes absorbed the volume expansion caused by freezing without rupture. The tubes regained their former size after melting had taken place.

No maintenance was required and no fouling material or deposits of any kind were observed on the tubes. The black PEHD tubing has also shown no propensity for photochemical degradation in sunlight. In this respect the facility has provided over four years of test exposure independent of other experimentation or operation of the unit.

Atmospheric effects have been experienced and include positive effects of rain-enhanced heat rejection. In combination with the chemical inertness of the polyethylene, this experience leads directly to the prospect of a viable deluge-assisted heat exchanger. Wind velocity-dependent disturbances were noted; however, instrumentation stability under those conditions deteriorated and quantitative measurements of wind effects have not been made. The phenomenon of recirculation was not discernible during the test series.

5.5.4 Concluding Remarks

Experience with the pilot plant encourages interest in the finless plastic tube heat exchanger. The absence of corrosion, recovery from the frozen state without damage and apparently low maintenance requirements are important advantages, which may contribute significantly to the overall economic rating of the system. Plastic tube heat exchangers for plants up to 1,000 MWe have been designed[15] as a consequence of encouragement provided by this research.

5.6 CONTACT WITH MANUFACTURERS: GEA-GESELLSCHAFT FÜR LUFTKONDENSATION mbH, BOCHUM, GERMANY

Date of Visit: April 3, 1975

Participants in the Discussion:
Mr. H.-H. von Cleve, Chief Engineer
DeSteese - PNL
Simhan - BF

5.6.1 General Remarks

GEA supplies a worldwide market for air-cooled heat exchangers and condensers. The robust hot-dip galvanized steel finned tube is favored for equipment with a service life expectancy of several decades. However, economic considerations govern most design decisions and GEA supplies aluminum finned tube heat exchangers to meet competition from other manufacturers.

5.6.2 Fouling Propensity

In nearly all industrial applications, airborne material will deposit on finned tube heat exchangers. The principal recommended method for cleaning is with pressurized water. Steel fins withstand the stresses imposed by this cleaning method better than aluminum fins.

5.6.3 Corrosion

Corrosion is the basic life-limiting process for any heat exchanger. GEA's general approach is to offer aluminum systems in applications which have amortization lifetimes of five to eight years and galvanized steel for typical power plant applications with lives of approximately 30 years. GEA is using a more representative laboratory simulation of corrosion-producing conditions to develop corrosion-resistant assemblies. In previously static tests, fin tubes were subjected to water immersion alternating with exposure in air. This was not fully representative of industrial exposure. The new laboratory test procedure models exposure in a flowing air environment.

5.6.4 Codes and Standards

GEA air-cooled heat exchanger and condenser systems are manufactured to the requirements of codes and standards imposed by regulatory authorities of the country in which the installation is to be made. German national standards cover 90 percent of the requirements of the rest of the world's authorities. Environmental standards apply principally to the control of noise emissions. Under certain conditions, boiler codes are applicable when sections of the cooling system are exposed to high pressure. Similarly, special qualification is needed when the system is associated with a nuclear plant. The Technische Überwachungsverein (TÜV) conducts the test procedures and certifies that equipment meets the necessary standards.

5.7 CONTACT WITH MANUFACTURERS: BALCKE-DÜRR AG (MABD), BOCHUM, GERMANY

Date of Visit: April 3, 1975

Participants in the Discussion:

Mr. G. Svenson, MABD

Mr. S. Kliemann, MABD

Simhan - BF

DeSteese - PNL

5.7.1 General Remarks

MABD is advancing the state of the art with the development of the cable net suspension dry cooling tower to be demonstrated at Schmehausen. The Schmehausen power plant is under construction and is designed to generate 320 MWe. The cooling tower is estimated to cost between DM 30- to DM 40-million out of a total plant cost of DM 1.5 billion. The rationale for dry cooling is a combination of water scarcity and the need for a large-scale demonstration of advanced technology.

The Schmehausen power plant, as a whole, is a large-scale demonstration of a high temperature gas-cooled pebble-bed reactor. Plant operation is anticipated in 1978. The tower is of the natural draft, indirect, cross-flow type, containing arrays of both MABD and GEA galvanized steel fin tube assemblies. Freeze protection will be provided by louvers (40 percent) and selective isolation and draining (60 percent) of the eight-section heat exchanger. Water-side corrosion will be suppressed with a nitrogen cover gas in drained sections.

Recirculation is not anticipated in the design of the tower, because towers greater than 150 feet generally have not shown this tendency. Recirculation in the past has only been noticeable with towers less than 115 feet, particularly with evaporative systems.

Environmental impact was considered during the design phase of this project. However, more climatological information would be of benefit to determine the environmental impact of the plant. An opinion was expressed that the nodes of the climatological map centered on areas of large population density (e.g. Frankfurt, Munich) are too far apart to accurately project conditions at intermediate locations.

MABD is active in advanced research and development of wet/dry systems, fan blade design and plastic tube heat exchangers. Plume abatement in evaporative towers is the objective of the MABD wet/dry cooling system. Another specific example is the development of larger diameter fans with special blade shape for noise reduction. These developments have the potential of reducing the environmental impact of dry cooling systems still further.

5.8 CONTACT WITH MANUFACTURERS: BALCKE-DÜRR AG (MABD), RATINGEN, GERMANY

Date of Visit: April 4, 1975

Participants in the Discussion:

Mr. F. Trage, MABD

Simhan - BF

5.8.1 General Remarks

Historically, this plant has specialized in boilers and still continues this line. The company is thus well equipped to deal with heat exchanger design problems. A highlight of the plant visit was the observation of a patented production procedure for the manufacture of finned tubes. In this process, fins are wound around elliptical tubes; thermal contact between tube and fin material is achieved through cold working. In the case of a steel fin-steel tube combination, subsequent hot dip galvanizing ensures protection against corrosion. A bath length of approximately 50 feet is the limiting factor on the length of the tube bundles.

5.8.2 Fouling Propensity

The problem of external fouling is not so critical in the case of MABD cooling equipment because the finned-tube arrays tend to resist the deposition of impurities. A dimensional control on this tendency is achieved by variation of fin height and spacing. Generally, these two parameters are connected by a hyperbolic relationship (fin height x fin spacing = constant). MABD prefers galvanized steel fin-tube assemblies for dry cooling equipment, because of the inherent robustness and the consequent possibility of withstanding periodic cleaning with pressurized water.

5.8.3 Corrosion

This is a problem which will always be present. The design philosophy in such a case should be to minimize corrosion during the economically useful life of the equipment which depends on the allowable depreciation rates. Thus different trends are observed according to national regulations and special industrial practices. In Federal Germany and especially in the chemical industry, a strong preference exists for galvanized steel assemblies.

5.8.4 Wind Effects and Recirculation

Recirculation is becoming a problem of decreasing importance because of the increasing height of dry cooling towers. For installations with forced draft similar to that at Wolfsburg, an inlet shroud seems to be a sufficient solution. Wind effects have been researched, but no systematic work has yet been undertaken to provide specific designs which eliminate the problems.

5.8.5 Freezing

Failures due to freezing must be attributed to improper operation because the present design and technology is sufficiently sophisticated to cope with the problem. MABD does not recommend the provision of louvers if they can be avoided. Louvers are examples of light mechanical engineering, and are difficult to incorporate in the structure of cooling towers which principally consist of heavy engineering components.

5.8.6 Maintenance Frequency and Availability

Forced-draft systems are generally more prone to failure, predominantly in the fans and bearings. In a comparison between direct-condensation and indirect systems, MABD feels that the former is more vulnerable because it contains long tube lengths under vacuum. Moreover, uncertain two-phase conditions can exist in the condensate. On the whole, however, maintenance is no major problem, and a dry cooling system of either type influences plant availability less than any other component in the power plant.

5.8.7 Codes and Standards

Reference was made to the manual for buyers of dry cooling equipment which has been prepared by VIK.

5.9 CONTACT WITH MANUFACTURERS: ITALIMPIANTI S.p.A., GENOA, ITALY

Date of Visit: April 14, 1975

Participants in the Discussion:

Dr. C. Rocco, Vice President

Dr. C. Roma, Professor of Nuclear Engineering, University of Rome

Dr. V. Leonelli, Senior Project Engineer

Dr. G. Caruso, Marketing Executive

Dr. G. Ristagno, Director

Dr. G. Daneu, Director

Dr. A. Corso, Director

DeSteese - PNL

5.9.1 General Remarks

This meeting included a discussion of the potential of plastic tube heat exchangers as conceived by Dr. Roma. However, the principal activity of the day was a working session to establish the wording of a technical information exchange agreement between Italimpianti and PNL. Technical discussions were limited to generalities pending the signing of the agreement by both parties. Quantitative data relating to the operation of plastic tube heat exchangers were revealed by Dr. Roma as reported in Section 5.5.

5.10 CONTACT WITH TECHNICAL ASSOCIATIONS

Associations were contacted personally, by correspondence and by telephone. The following paragraphs summarize those contacts.

DECHEMA-Apparatebau has a subcommittee which deals with problems of heat exchangers in general. Dry cooling equipment does not figure as a subject of special importance. The subcommittee cooperates closely with the VDI (Verein Deutscher Ingenieure) which, in turn, is represented by a similar subcommittee, both having common members. Representatives of the chemical and petrochemical industries, equipment manufacturers and university experts serve as members of these committees. This ensures that acute problems and trends, as far as they are not in conflict with individual competitive interests, are addressed on a timely basis. After identification, these problems are recommended for further research supported by private, pooled or governmental funding. These expert subcommittees therefore play a powerful role in coordinating the approach to advancing heat exchanger technology.

Dry cooling equipment is the special field of the VGB (represented through a sister organization VIK) and the VDEW. Because water scarcity is a national problem, it follows that dry cooling equipment research is part of the Federal government effort to standardize the design with a unit size between 1000 and 1200 MW. A special subcommittee is responsible for the coordination of dry cooling research and development. The general trend is toward the organization of consortia to build major dry cooling installations, as illustrated by the example of Balcke-Dürr/GEA collaboration at Schmehausen.

5.11 MEETING AT BATTELLE-GENEVA (BG), SWITZERLAND

Date of Visit: April 10, 1975

Participants in the Discussion:

Mr. J.-L. Meylan, Manager, Mechanical Engineering Research Department

Mr. J.-P. Budiger, Section Leader, Mechanical Engineering Research Department

Mr. W. H. Frost, Staff Member, Mechanical Engineering Research Department

DeSteese - PNL

5.11.1 General Remarks

The discussion centered on a novel hybrid cooling system still in the research stage at BG. They hybrid tower concept includes two separate zones of heat exchange:

- a wet zone in which the hot water is cooled by evaporation into the circulating air;
- a dry zone, where the air-vapor mixture is subsequently heated to lower its relative humidity.

The saturated air in the tower is dried in a cross-current heat exchanger consisting of thin vertical plastic sheets (thickness $\sim$0.2 mm): one side supports a film of water, the other serves as one of the walls for the passage of air. These sheets are joined in twos to make up an airtight enclosure which presses itself against a network of cables under the action of a slight overpressure. The cable network situated at the boundaries of the air passage contributes to local turbulence and hence more effective heat exchange.

Water is distributed to the inside of the envelopes by perforated tubes with the possible addition of capillary material to ensure the uniformity of the created film. These envelopes are suspended in the interior of a tower similar to the wet hyperbolic cooling tower. Their height is limited to about 10 m to avoid excessive pumping requirements. The lower edges of the plastic sheet envelopes are immersed in a collecting basin, thus rendering them airtight under the existing overpressure.

Research to date has concentrated on methods of distributing the cooling water and observation of water film stability when flowing on vertical plastic sheets. This concept still requires considerable effort to establish its basic feasibility; however, the novelty of the approach warrants further consideration.

6.0 PHASE II INTERVIEWS

This section contains a chronological summary of interviews conducted as part of Phase II activities. Information about operating experience with dry cooling equipment was obtained from plant personnel at 14 European sites.

6.1 DRY COOLING EQUIPMENT IN THE INDUSTRIAL POWER PLANT OF DAIMLER-BENZ AG, SINDELFINGEN, GERMANY

Date of Visit: September 22, 1975

Participants in the Discussion:

Ing. H. Diehl, Power Plant Manager

Dipl.-Ing. Wenzel, Deputy Manager and Thermal Analyst

Mr. Seiffert, Water Chemist

Simhan-BF

6.1.1 General Remarks

The Daimler-Benz AG automobile factory at Sindelfingen depends upon the east power plant for process steam, steam heating and electric power. The demand for steam varies as a function of ambient temperature; the summer demand is about 20 percent of the winter peak figure. Process steam is supplied at three different pressures: 352 psia, 126 psia and 52 psia. The power plant was constructed in three sections during 1959/61, 1961/63 and 1969/72 with three different sizes of Benson oil-fired boilers (2 x 60 t/h, 2 x 80 t/h and 2 x 150 t/h, respectively). Steam conditions at the boiler outlets in the first two sections are identical at 980°F and 1120 psia. The boilers of the third section deliver steam at 990°F and 1730 psia.

The operational philosophy of the power plant is as follows. The back pressure turbines, which are bled to meet the process and heating steam requirements, provide the average electric power demand of the manufacturing plant during the winter months, while the peak winter demand is supplied by the utility grid. The last turbine stages (condensation stages) are used mainly in the summer, when steam capacity in excess of average winter requirements may be used to generate electric power.

The third power plant section contains two turbines. One 30 MWe turbine operates solely under back pressure and delivers all of its steam to the production steam grid. The second turbine, connected to the 52 psia steam line, operates only when surplus steam is available after meeting the production demand. In this case, it delivers 5 MWe, discharging a mass flow of 34 t/h into the dry cooling equipment.

Dry cooling equipment was erected in three sections corresponding to the construction of the power plant sections. The equipment was manufactured and delivered by GEA, and is a direct condensation system with forced draft. Details of the dry cooling equipment are listed in Table 6.1-1.

The power plant layout and location were primary reasons for the selection of dry cooling equipment. The plant is situated inside the compound of an automobile factory and in the immediate vicinity of extensive parking lots for new cars just off the production lines awaiting dispatch (Figure 6.1-1). Evaporative towers would generate the risk of moisture transport which would damage the finish of these vehicles. Sindelfingen lies on the edge of the Swabian Alp plateau, which has only meagre groundwater resources and almost no other sources of cooling water. Daimler-Benz management sets a very high priority on showing good taste in the general architectural design of the factory complex and avoids construction features which grossly emphasize the technical function of the plant.

6.1.2 Water Quality and Internal Corrosion

Feed and makeup water are subjected to a comprehensive water treatment process specified by the VGB. The achieved water quality satisfies standards considered necessary for Benson forced-convection boilers. Almost all of the heating steam and a major part of the product steam form a closed system. The following data typify the water quality maintained in this plant:

pH	8.7-9
Hydrazine	traces
Alkalinity (NH_3)	1 mg/ℓ
Silicates	0.01 mg/ℓ
Fe+++	0.02 mg/ℓ
O_2	not measurable
Conductivity	0.1-0.15 μmho/cm
Residual hardness	not measurable

TABLE 6.1-1. Daimler-Benz Industrial Power Plant Dry Cooling Equipment Details

	Stage 1 1959/61	Stage 2 1961/63	Stage 3 1969/72
Air Flow	Forced draft	Forced draft	Forced draft
Tube/fin specifications	GEA galvanized steel elliptic tube/steel fin	GEA galvanized steel elliptic tube/steel fin	GEA galvanized steel elliptic tube/steel fin
Tube arrangement	45° Delta	45° Delta	45° Delta
Tube length	4.7 m	6 m	6 m
Tube layers	3x staggered	3x staggered	3x staggered
Steam conditions			
vacuum (design)	0.08 ata 96°F 8% moisture	0.08 ata 96°F 8% moisture	0.08 ata 96°F 8% moisture
ambient air temperature	65°F	65°F	65°F
Fans			
number	3	3	3
diameter	4700 mm	5500 mm	6000 mm
fan speed	196rpm	170rpm	170rpm
speed change	2 speeds, pole variation	2 speeds, pole variation	2 speeds, pole variation
fan power	3 x 25 kW	3 x 40 kW	no information
air flow	3 x 174 m^3/s	3 x 227 m^3/s	no information
head	4 in. WG	5 in. WG	no information
Steam flow (design)	13.5 t/h	18.3 t/h	24.5 t/h
Heat rejection (design)	29.4×10^6 Btu/h	38.3×10^6 Btu/h	51.3×10^6 Btu/h
Maximum steam flow	18.3 t/h	25.5 t/h	34 t/h
Maximum heat rejection	41.4×10^6 Btu/h	53.4×10^6 Btu/h	70.3×10^6 Btu/h

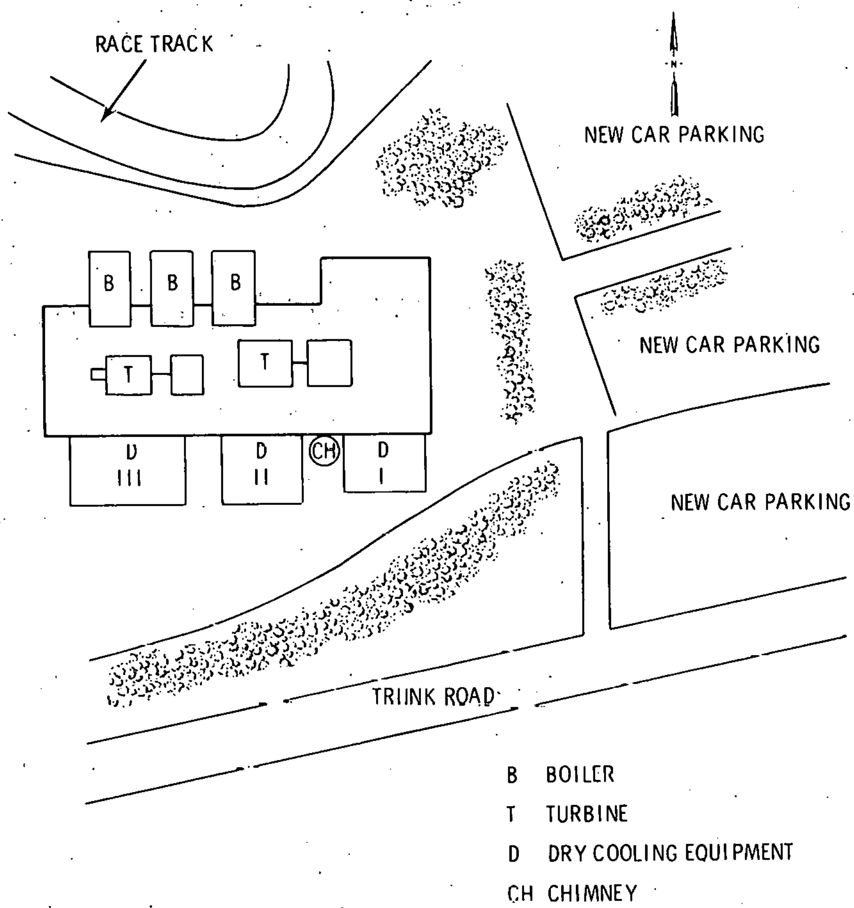


FIGURE 6.1-1. Power Plant Layout at Sindelfingen

Turbines, condenser headers, and connecting steam lines are inspected after intervals corresponding to 25,000 hours' operation. These maintenance checks, performed during scheduled plant shutdown and overhaul periods, have revealed no internal corrosion or fouling. The power plant management adheres to the philosophy of maintaining the best quality of feed water despite the costs involved, to assure maximum availability of the forced convection boilers which supply process steam.

The extensive water treatment plant handles an average of 10,000 m^3 every month. The plant consists of the following components:

- Electromagnetic filter
- Anion exchanger
- Cation exchanger
- Degassing equipment

Process steam condensate, which does not form part of the closed system, is recovered wherever possible and sent through the water treatment loop. Hence only a minor fraction of the water turnover must be made up by raw water addition which costs DM 1.50/m^3. Materials and labor costs (no equipment amortization) for water treatment are about DM 0.40/m^3. One man is assigned fulltime on a 12-hour shift basis to be in charge of the water treatment equipment. During office hours, a laboratory assistant does the routine analysis. The whole section of five men is headed by the water chemist. Electrical conductivity is monitored hourly and as much hydrazine as necessary is added to maintain a negligible oxygen content.

Two Elmo pumps and three steam ejectors maintain vacuum and also act as deaerators. During shutdown periods, hot dry air is circulated through the dry cooling system to avoid internal corrosion.

6.1.3 Air-Side Corrosion and Fouling

The air quality at the plant site corresponds to the semi-industrial environment of Sindelfingen. According to information available, no undue SO_2 concentration has occurred, even during calm weather conditions which average 30 days/year. Close visual inspection of even the oldest (1959) dry cooling installation shows no signs of corrosion.

The Sindelfingen plant is plagued by an unusual source of air-side fouling, especially during the critical summer months when the dry cooling system is operated at the greatest load. Numerous poplar trees growing in the immediate vicinity of the power plant produce a fine cotton-like product from the ripening pods. This material nests in the interstices of the finned tubes, trapping dust and leaving a matted deposit on cooling surfaces. This leads to a progressively decreasing performance of the condenser, in which the vacuum degrades typically from 92 percent to 85 percent.

The air-side deposits are generally cleaned once a year in midsummer. A four- to six-man team is required. Water jets with a total head of approximately 800 psia are used. It appears that a normal detergent is added to the water. The cleaning jets are directed first in the air-flow direction and then in the counter-flow direction. The labor costs for cleaning are about DM 4,000. Cleaning is performed on weekends with the condenser section shut down.

6.1.4 Freezing Experience

During the last 15 years, plant personnel have gained sufficient experience to cope with freezing problems. This ability has been helped by retrofit changes to the condenser in the first power plant section. This condenser was originally designed for parallel steam and condensate flow. This led to serious freezing problems in the severe winter of 1962. Slugs of ice formed first inside the tubes next to the fan. Ice formation then progressively advanced to the other layers. Burst tubes were repaired temporarily with adhesive tape. Permanent repairs involving welding and painting the welds for corrosion protection were completed during the annual shut-down for cleaning.

No cost figures are available for this repair sequence. To solve the problem of freezing, counterflow (Dephlagmator) condenser elements were retrofitted in two-thirds of the condenser. No cost information for this alteration was available.

The condenser installed in the second power plant section contained only counterflow elements to overcome the freezing problem. However, the condenser associated with the third plant section is designed to be similar to the first section retrofit arrangement.

Freezing is prevented by control procedures including fan speed regulation and by covering the heat exchanger surface with tarpaulins. The louvers originally built in the first section condenser have been discarded. Resistance thermometers placed in the headers and in critical elements provide advance warning of potential freezing conditions.

6.1.5 Recirculation and Wind Effects

Evidence of recirculation has been observed at the Sindelfingen plant. Typically, a decrease of vacuum from 95 percent to 92 percent results. All three condensers seem to be involved, although not simultaneously. Opinion is varied as to whether this effect can occur in periods of calm weather as well as on windy days when the wind direction places the condensers in the wind shadow of the power plant building. All the condensers are mounted on reinforced concrete pillar structures and the fan inlet shrouds are surrounded by a narrow skirt. Eternit wind shields surround the condensers to a height of about two-thirds of their vertical dimension.

The power plant building and separate structures supporting the dry cooling equipment are situated with their longitudinal axis in the direction ENE-WSW (Figure 6.1-1). Prevailing winds are either from the NW or from the NNE. Better vacuum performance is always associated with the winds from NNE. It is difficult to identify the extent to which this effect can be attributed to the wind or to a lack of recirculation.

6.1.6 Concluding Remarks

Regular maintenance and repair costs associated with the dry cooling equipment are not accounted for separately. Maintenance is performed continuously by a maintenance team, which checks the gear boxes and renews the lubrication. It is important to note that only the fan motor/gear train system of the dry cooling equipment require significant attention. On the average, about 2 fans out of 11 demand some kind of major attention every year. About four man-weeks of effort costing DM 8,000 is usually sufficient to take care of these problems.

The availability of the plant, which is rated at about 89 percent, is not influenced by the operation of the dry cooling equipment.

The entire plant, including the boilers, buildings, turbines, and auxiliary equipment, involved an investment of DM 26 Million. Of this, about DM 6 Million was spent for the turbines, DM 1.3 Million for the dry cooling equipment and DM 300,000 for steam lines.(16)

6.2 DRY COOLING EQUIPMENT AT THE HAUSHAM POWER PLANT, HAUSHAM/SCHLIERSEE, GERMANY

Date of Visit: September 23, 1975

Participants in the Discussion:

Mr. Weigl, Deputy Plant Manager

Mr. Biniek, Shift Foreman

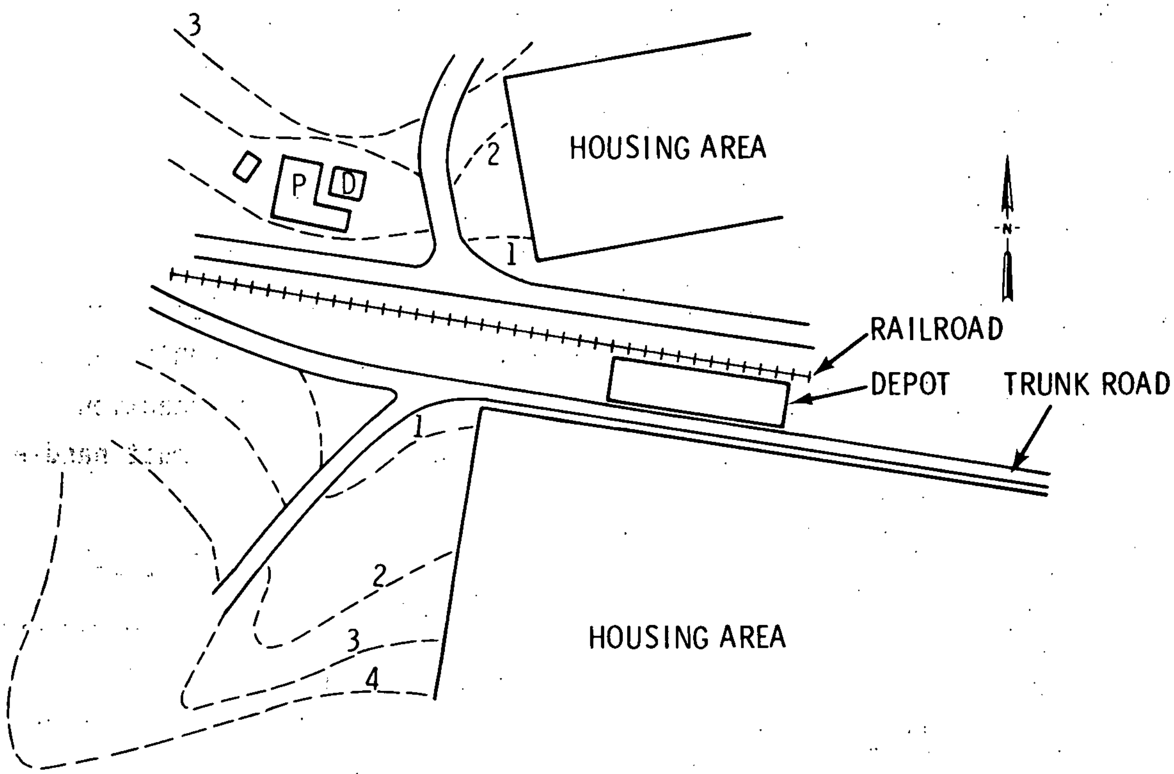
Mr. Metzger, Water Laboratory

Simhan - BF

6.2.1 General Remarks

The Hausham power plant was completed and began operation in 1962, mainly to supply electrical power required at a nearby coal mine. Pulverized coal from this mine was used as fuel. Mining operations ceased in 1969 as a result of adverse market conditions. The power plant was then converted to burn crude oil. Ownership changed and the Peisenberger Kraftwerksgesellschaft (a subsidiary of Isar-Amper Werke AG) assumed control of the plant. Following the change in ownership, electricity generated at Hausham was delivered to the Bavarian State grid, providing a small fraction (45 MWe) of the base load. The rise in the cost of oil following the oil crisis of 1973-74 resulted in the power plant being taken out of regular commission. After a thorough overhaul, which was in progress during this interview, the power plant will be operated as a peaking power plant.

Hausham lies in a valley which runs roughly in an east-west direction (Figure 6.2-1). The land level rises gradually toward the east. At the western extremity of Hausham, another valley branches off towards the southwest. The power plant is in the northern half of the main valley on an elevated location just opposite the entrance of the branch valley. This fact is important in connection with freezing and recirculation effects to be discussed later. Installation of dry cooling equipment was imperative because the Hausham valley has no running water resources, and the use of water from Schliersee (8 km distant) was considered prohibitively



P POWER PLANT

D DRY COOLING EQUIPMENT

FIGURE 6.2-1. Hausham Power Plant Location

expensive. Moreover, the plant is situated in the immediate vicinity of housing areas. Wet cooling towers with attendant plumes would have been undesirable in the narrow valley.

6.2.2 Water Quality and Internal Corrosion

The plant contains a single Benson forced-convection boiler of 40 MWe nominal capacity. This type of boiler requires feed water of very high quality. This quality is assured by the use of an extensive water treatment unit consisting of an anion exchanger, a cation exchanger and degassing equipment. A typical feed water analysis is:

pH	9.5
p-alkalinity	4 mg/ℓ as $CaCO_3$
m-alkalinity	7.5 mg/ℓ as $CaCO_3$

Silicates	0.023 mg/ℓ
Fe+++	0.043 mg/ℓ
O_2	0.003 mg/ℓ
Conductivity	0.02 μmho/cm
Residual hardness	not measurable
Hydrazine	0.12 mg/ℓ

Output up to 45 MWe can be accommodated under favorable conditions. Boiler outlet conditions are steam capacity 140 t/h at 2120 psia and 990°F. Reheat conditions are 525 psia and 610°F. The turbine is bled in the reaction stages for feed water heating. The direct condensing equipment must handle only 90 t/h of condensate under design conditions.

The details of the dry cooling equipment are listed in Table 6.2-1.

Plant personnel report no signs of internal corrosion from observations made during the general overhaul after about 30,000 hours of operation. However, conflicting statements were also made regarding startup conditions of the power plant after temporary shutdowns. It is alleged that about 10 liters of rust slurry must be removed from the condenser after each event. The origin of this rust is uncertain. It is interesting to note that, during shutdown periods, dry air is not circulated through the dry cooling equipment as is done at the Daimler-Benz plant.

The water treatment unit handles an average of about 26 t/h makeup water, drawn from ground water wells. Water analyses are made only during the day shift and the entire chemistry of the plant is the responsibility of a single laboratory assistant supervised, in turn, by the plant manager. The electrical conductivity of the feed water is measured continuously and is displayed on the control panel. Regular shift attendants dose enough hydrazine to keep conductivity at the desired level. The costs of makeup water should be about DM 1.50/m^3 but exact figures could not be established. The same is true for the water treatment costs.

6.2.3 Air-Side Corrosion and Fouling

The environment of the plant at Hausham is rural. Although the housing around the plant depends on oil heating, no significant concentrations

TABLE 6.2-1. Hausham Power Plant Dry Cooling Equipment Details

Installation Date	1962
Forced draft air flow	
Tube/fin specification	GEA galvanized elliptic steel tube/steel fin
Tube arrangement	3 parallel 60° deltas
Tube length	6 m
Tube layers	4 staggered
Heat exchange, air-side area	100,000 m^2
Module arrangement	24 modules/delta (20 parallel flow modules, 4 counterflow modules)
Steam conditions	
vacuum (design)	0.08 ata 96°F 8% moisture
ambient air temperature	60°F
Fans	
number	9
diameter	6 m
fan speed	147 rpm
air flow	3000 m^3/s
head	18 mm WG (4.5 in. WG)
installed fan power	580 kW
Steam flow (design)	90 t/h
Heat rejection (design)	160 x 10^6Btu/h[a]
Maximum steam flow	~100 t/h
Maximum heat rejection	175 x 10^6Btu/h (low ambient air temperature)

(a) Originally designed to operate with additional water sprays during summer.

of SO_2 and nitrogen oxides affect the air quality. Weather conditions, including 30 days/year calm weather with inversion heights up to 1200 m, are favorable to good air quality. Under these circumstances, it was not surprising to note that air-side corrosion was practically nonexistent.

The plant at Hausham has to deal with air-side fouling in much the same way as at Sindelfingen. The main deposit on the fins and tubes consists of dust, small insects and leaves. Two moving galleries have been installed on each of the three deltas. Each gallery is equipped with a spray system and is supplied with water at a pressure of 240 psia. Heat exchanger surface cleaning is done twice every summer. A total of 320 man-hours costing approximately DM 6400 per annum is required. Regular unskilled maintenance personnel are employed in this activity. Because the cleaning is carried out while the condensing units are in operation, only treated water is used for spraying and the fans are switched off in the modules being cleaned.

Water spray rings were mounted on the entrance shrouds of all nine fans and connected to a raw water supply with a total head of 240 psia to provide deluge-type cooling in the summer. Initial experience showed that part of the sprayed water tended to collect in the fan hubs causing unbalanced fan rotation with subsequent frequent failures of the terminal bearings in the gear box. Drain holes in the hubs remedied this situation. Hybrid operation, however, ceased after use during the first summer, because a progressive deposition of calcium carbonate was noticed. Estimations of the expected increase in air-side heat transfer coefficients are not available. However, plant personnel stated that about 2 percent better vacuum (87 percent instead of 85 percent) was achievable with hybrid operation.

6.2.4 Freezing Experience

Freezing was openly acknowledged as a problem at the Hausham plant. To interpret freezing experience at Hausham, the following description of the plant layout should be helpful.

The longitudinal axis of the boiler house and turbine building run approximately in the north-south direction (Figure 6.2-2). The administration building is lower than the boiler house and is attached to the boiler-turbine house at the south to form a very short L-shape. The dry cooling equipment is erected on a reinforced concrete pillar structure in the enclosed space formed between the two arms of the L. The longitudinal axes of the three deltas are parallel to one another and run in an east-west direction. The deltas stand above the roof line of the administration building. The cooling modules, which project their full area to winds from the south or the southwest, are sheltered through Eternit wind shields which surround the rectangle formed by the elevated mounting base of the cooling equipment. The height of these shields is about two-thirds the height of the deltas.

Two distinct freezing situations can be associated with specific wind conditions. Cold east winds usually cause freezing in the cooling tubes on modules toward the inside walls of the central delta, as well as the northernmost delta. Freezing which results from south or southwest winds has been noticed in modules on the southern side of the central delta. As many as 16 frozen tubes have been experienced in the last 12 years of operation.

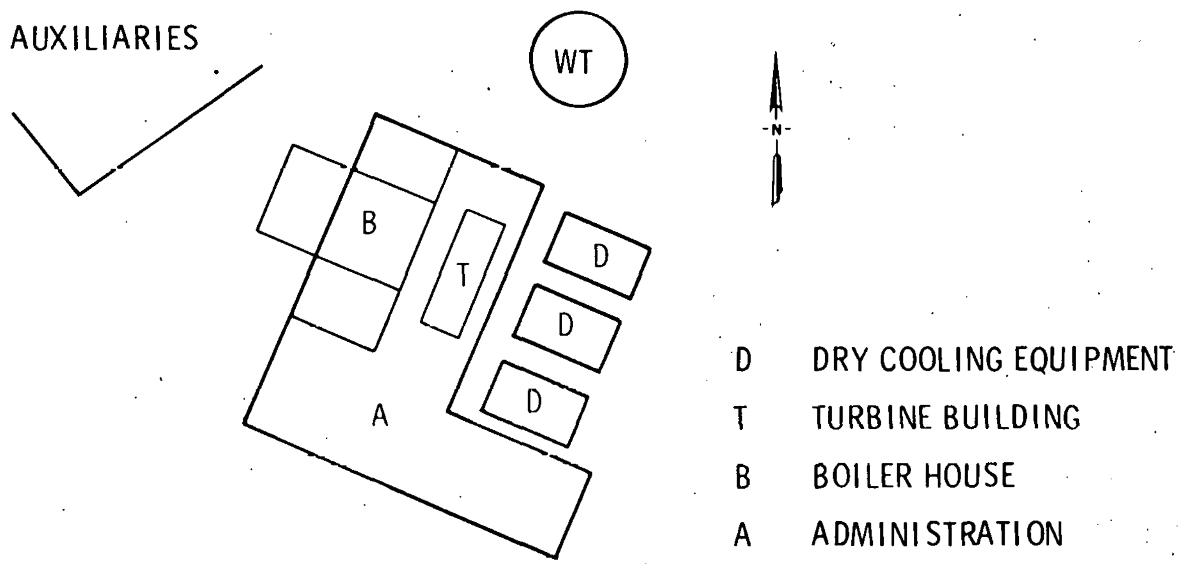


FIGURE 6.2-2. Hausham Power Plant Layout

The yearly frequency of freezing events has decreased with increasing experience. Control procedures include the use of resistance thermometers in the condenser headers, providing a remote display of temperatures on the control panel. When the weather situation warrants, fans are switched off progressively and as a final resort, condenser sections are covered with tarpaulins. No single freezing incident has caused a plant shutdown and any ruptured tubes are easily sealed temporarily with adhesive tapes. Permanent tube repairs are carried out by GEA; no cost data were available.

6.2.5 Concluding Remarks

The freezing experience at Hausham shows that the local wind situation and the micro-aerodynamics around the dry cooling equipment are important design factors. Recirculation and wind effects other than freezing events have not been examined closely. This can probably be attributed to the system of cost accounting adopted by the plant, which does not separate maintenance costs of the dry cooling equipment from other operational expenses. A permanent eight-man team maintains the plant and the dry cooling equipment.

6.3 DRY COOLING EQUIPMENT IN THE WASTE-BURNING PLANT, CITY OF VIENNA, AUSTRIA

Date of Visit: September 24, 1975

Participants in the Discussion:

Ing. Carl Zapletal, Plant Manager

Senatsrat Seidl, Head of Department 48,[a] Magistrat of the City of Vienna

Simhan-BF

6.3.1 General Remarks

The waste-burning plant of the City of Vienna is situated in the middle of a residential area and incinerates about 50 percent of the wastes of this Austrian metropolis. Three natural circulation boilers are fueled with waste material and have a maximum steam capacity of 35 t/h at 255 psia and 590°F superheat. Most of the steam is used for heating municipal institutions such as the hospital and city laundry. A 3.5-MW capacity turbine generates electricity when surplus steam is available. This occurs approximately seven months per year, with no operation during winter. The condensation unit attached to the turbine is an indirect condensation unit based on the Hungarian Heller-Forgó system. Cold water at 140°F is sprayed into the condenser and the mixture of condensate and spray water enters the natural draft dry cooling tower at a temperature of 185°F. A novel feature is the cooling tower with a square cross section (Figure 6.3-1). The northwest corner of the boiler house, as originally built, had a niche of square cross section. This space is now occupied by the cooling tower.

The height of the tower (28 m) is equal to the height of the rest of the boiler house. Consistent with the integration of the cooling tower with the power house building configuration, cooling deltas are accommodated on the western and northern flanks of the tower. Instead of louvers on the cooling deltas, the upper half of the eastern flank is fitted with bypass vanes to reduce air flow through the deltas. The unit went into operation

(a) Department 48 is for municipal cleaning.

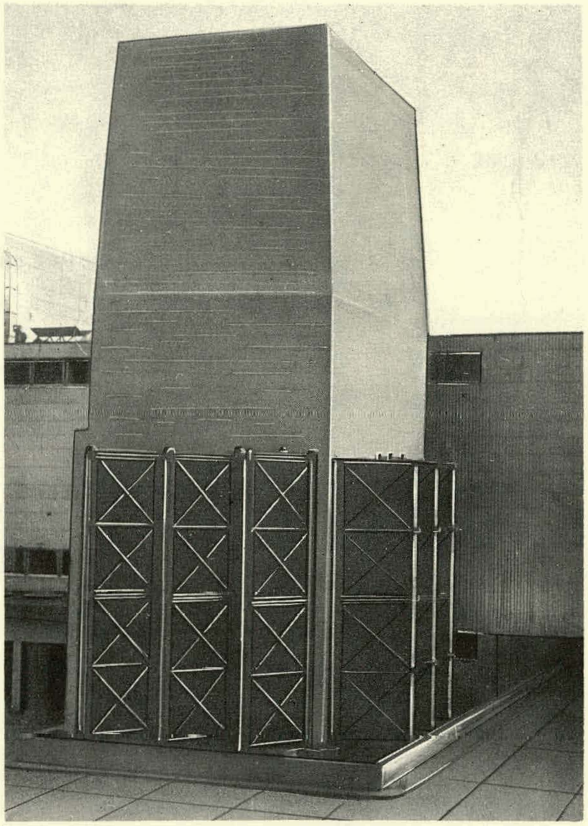


FIGURE 6.3-1. City of Vienna Waste-Burning Plant Dry Cooling Equipment

in 1966/67. The principal criterion for the adoption of dry cooling was the necessity of avoiding vapor plumes in residential districts. Details of the dry cooling equipment are summarized in Table 6.3-1.

6.3.2 Water Quality and Internal Corrosion

The boilers of the plant are based on natural circulation. The ratio of heat release to unit heat exchanger area in the combustion-radiation section does not appear to be high. Therefore, constraints on water quality to be maintained are not very severe and the water treatment plant is correspondingly simple. Another reason for choosing a boiler system adequate to cope with a low quality feed water is that about 8 percent of the steam capacity is lost in the process steam grid and nearly 35 tons of make-up water must be treated and fed into the steam loop daily. Approximate

TABLE 6.3-1. City of Vienna Waste-Burning Plant Dry Cooling Equipment Details

System description	Heller-Forgó, spray condenser, natural draft cooling tower
Tube type	Forgó aluminum tube/aluminum fin
Module height	10 m (2 tube bundles 5 m in length, flanged together in the middle)
No. of modules	12 (6 deltas)
Tube arrangement	vertical
Tube layers	3 staggered
Angle of deltas	60°
Water temperature	inlet: 185°F outlet: 140°F
Water circulation	1100 m^3/h, 1 turbine-driven circulating pump, no recovery turbine
Design heat rejection	96.3×10^6 Btu/h

water costs are:

- Raw water - DM 0.80/m^3
- Treatment - DM 0.20/m^3

The water treatment unit consists of an anion exchanger and a low pressure degassing unit. It could not be determined whether there was a constant check on the water conductivity in the steam loop. Sufficient hydrazine is added to the make-up water to assure a slight excess of hydrazine content in the water of the steam loop. Details of the feed water analysis as recorded in the plant are:

Residual hardness	0.01 mg/ℓ
m-alkalinity	10 mg/ℓ as $CaCO_3$
p-alkalinity	35 mg/ℓ as $CaCO_3$
P_2O_5	0.01 mg/ℓ
O_2	0.1 mg/ℓ
pH	9.1
hydrazine	traces

Available information confirms that no problem of internal corrosion has been experienced with the dry cooling equipment. Plant management seems to be less aware of the possibility of corrosion in the boiler-turbine section which may result from a relatively high oxygen content. This could bring a deposit of rust into the condenser and dry cooling equipment leading to possible internal fouling.

6.3.3 Air-Side Corrosion and Fouling

As is common practice with Heller systems, the dry cooling coils consisting of 99.5 percent aluminum tubes and fins were treated by the MBV aging process in which a resistive coating (patina) is formed, preventing further corrosive deterioration of the air-side heat exchanger surfaces. No other coating against corrosion (in contrast to Rugeley) has been provided for.

The environment of the plant at Vienna is that of a mainly residential suburb with small-scale industry. Whereas the SO_2 content of the air can be high as a result of oil-fired domestic heating units in this particular suburb, the dust content is normal in terms of urban standards. The fuel firing system of the plant is equipped with wet ash and slack removal, and filter units preceding the stack. The 85-m stack provides very effective dispersion and does not cause local fallout of dust. Hence, the dry cooling equipment is not subjected to unusual dust loads.

Under the above conditions, air-side corrosion has not become apparent during the last 8 years of operation. Plant management also expects no future problems of air-side corrosion.

According to information provided by management, air-side fouling has also been negligible. The deposit on the air side consists mainly of urban dust, which, in conjunction with atmospheric organic residues, gives rise to a slightly pasty coating. Apparently, as a result of a good draft, air velocities through the heat exchanger coils are high enough to impede the buildup of heavy coatings. Therefore, air-side cleaning is necessary only once every two years. Untreated water from fire hydrants at 80 psia and

~60°F is used as the cleaning agent under normal fire hydrant nozzle pressure. An 8 to 12-hour shift with two unskilled men costing approximately DM 400 is adequate to perform this job.

6.3.4 Freezing Experience

The dry cooling equipment in Vienna has never operated during the winter months. Hence, no freezing experience can be reported. During the winter, the equipment is drained. Specific efforts to protect the steam-side heat exchange area against corrosion during downtime have not been considered necessary.

6.3.5 Concluding Remarks

The high stack, as well as the relatively high air velocities, are probably responsible for the absence of recirculation effects. With prevailing winds mainly from the northwest and the consequent similarity of the air flow in both northern and western deltas, the absence of wind influence on cooling performance is to be expected.

Vienna was an example of equipment delivered by Transelektro, the Hungary Trading Company for Electrical Equipment and Supplies. Generally, equipment of this origin has the following features:

1. Water lines of externally galvanized ferrous material connecting the cooling deltas.
2. Finned tubes of 99.5 percent aluminum between aluminum headers.
3. Nonmetallic connections between ferrous and aluminum parts.
4. Vulcanized rubber O-ring gaskets between tubes of adjoining segments in the cooling deltas.
5. Air vents and drainage valves in the headers and the water lead lines with vents and valves in general also having rubber seals.

The main repair problem at Vienna seems to result from frequent water leakage at the seals and gaskets in items 3, 4 and 5. Apart from a probably short life characteristic of the sealing material, the cause seems to be occlusion of solid particles in the seating surfaces. This opinion was not corroborated by plant personnel. Cost figures for such maintenance are also not available; however, no plant downtime appears to result from such frequent seal failures.

6.4 DRY COOLING EQUIPMENT AT THE STEEL WORKS IN DUNAÚJVÁROS, HUNGARY

Date of Visit: September 25, 1975

Participants in the Discussion:

Dipl.-Ing. Kádi, Power Plant Superintendent

Dipl.-Ing. G. Tomcsanyi, HÖTERV (Hungarian Institute for Power Plant Design)

Simhan-BF

6.4.1 General Remarks

The power plant, situated in the middle of a steel works complex, generates electricity primarily through backpressure turbines. The steam bleeds at three different pressures to meet product steam demands. A battery of six natural convection boilers (2 x 100 t/h, 4 x 50 t/h) fired mainly with blast furnace gas and auxiliary crude oil burners generates steam at 815°F and 540 psia. The generated steam, of which about 80 percent is process steam, drives four backpressure turbines and two 16-MWe condensing turbines. The dry cooling equipment handles the steam condensate of one of these condensing turbines.

Dry cooling equipment was installed at Dunaújváros for two reasons. First, the steel plant at Dunaújváros lies on the elevated bank of the River Danube, which flows through a comparatively narrow and steep valley. The first 16-MWe condensing turbine was installed with a conventional surface condenser using cooling water from the Danube. Apart from long distance transport of cooling water, a difference of 26 m between the condenser and the mean water level of the Danube was a serious drawback. An additional problem was undue fouling of the condenser tubes on the cooling water side, which resulted in "longer than normal" downtime for maintenance. The concept of once-through cooling was thus abandoned for the second 16-MWe condensing turbine.

Second, the scarcity of cooling water in Hungary has always been a strong motivation for the advancement of dry cooling equipment. The plant extension at Dunaújváros was a welcome opportunity to construct a dry cooling tower of greatly increased capacity than the state-of-the-art. In comparison with its predecessor situated in a textile factory in Budapest (now a technical monument), the Dunaújváros dry cooling equipment represented a 20-fold increase in heat rejection capacity. In fact, the dry cooling tower at Dunaújváros built in 1961 can be considered as the first full-scale Heller-type tower.

The design details of the dry cooling tower at Dunaújváros are listed below.

Year of commission:	1961
Type:	Natural draft concrete dry cooling tower based on the Heller-Forgó system with indirect condensation
Tower dimensions:	Base diameter 42 m, approximately cylindrical tower with very slight taper, height 65 m
Tube specification:	Aluminum tube/aluminum fin with aluminum spacer ring. Thermal contact between tube and fin achieved in two ways: (1) plastic compression through spacer ring and (2) extension of internal tube diameter. Tube diameter: 15 mm ID; wall thickness: 0.75 mm
Module details:	The modules are arranged in vertical deltas with an included angle of 60°. Each module consists of two cooling tube bank segments 5 m long and flanged together in the middle with O-ring gaskets. The other ends of the tubes are welded to aluminum headers. Module width is 2.8 m. Most modules have three tube layers in a staggered configuration. Modules with four tube layers are also present. The reasons for such modules and their exact location could not be ascertained.

Number of deltas:	42. The cooling deltas are equipped with manually operated louvers.
Heat rejection capacity:	106×10^6 Btu/h. Design vacuum, 94 percent
Load variation:	Practically none (base load electric power generation)
Water flow:	3600 m^3/h with flow direction bottom-to-top
Ambient air temperature:	50°F
Water temperature:	Inlet: 95°F; outlet: 80°F.
Special features:	One condensate pump (3600 m^3/h, 60 psia) and one recovery turbine. The water flow is distributed over four independent coolant loops with the possibility of an individual closure of each loop. The corresponding cooling deltas are distributed quandrantwise around the base circumference. To facilitate individual regulation of air flow through the deltas of each coolant loop, walls have been erected inside the cooling tower over its total height along two mutually perpendicular diameters. Air guides inside the cooling tower have been installed to achieve an efficient 90° direction change of the air flow from the cooling deltas into the cooling tower stack.

6.4.2 Water Quality and Internal Corrosion

The natural circulation boilers do not require stringently maintained water quality. In addition, a major portion of the steam produced serves as process steam having an inevitable loss fraction. As a result, water treatment is not very comprehensive. The water treatment unit consists mainly of an anion exchanger and degassing equipment. The control of water quality appears to be based only on single daily analysis with the measurement of a few pertinent parameters. The following typical water quality data were obtained.

pH	7-8.5 (strict upper limit)
Residual hardness	negligible
O_2	1.5 mg/ℓ
SiO_2	1.2 mg/ℓ
Conductivity	1-3 μmho/cm

Plant management stated that internal corrosion and fouling have not been problems. It is uncertain, however, whether regular checks to ascertain the status of the internal heat exchange areas have ever been undertaken.

6.4.3 Air-Side Corrosion and Fouling

The air-side environment at Dunaújváros typifies the most severe conditions under which dry cooling equipment must operate. The cooling tower is situated about 200 m from the power plant building. The whole power plant is in the center of the steel works and near blast furnaces, Bessemer converters and Martin furnaces. The SO_2 concentration as well as the dust content of the air are definitely very high. Additional severe dust loads are caused by an ore-dressing plant located about 400 m from the tower toward the northwest, the same direction as that of the prevailing winds. The cooling tower also operates near a gas washing column which emits very fine water droplets.

The finned aluminum tubes have been treated by the MBV process to withstand corrosion. This seems to have provided adequate protection against corrosion even under the severe conditions mentioned above. Plant management reports no repair or maintenance problems in connection with external corrosion. It is thought that with the cooling tower now out of operation, a certain deterioration of the external heat exchanger surface can take place, as the surface temperatures are frequently below the dew point.

Fouling on the air side is the most serious maintenance and operation problem at Dunaújváros. During peak conditions, the vacuum achievable in the condenser falls to about 85 percent from a design vacuum of 94 percent. The deposits on the air-side heat exchanger surface consist of ore dust, which is baked to form a continuous layer about 1/4-mm thick. Close inspection showed that scratching with a fingernail causes the layer to peel and fall off. To deal with these layers, plant personnel have designed and constructed a mobile cleaning rig. Untreated Danube water is directed against the cooling deltas in both directions[a] under a total head of about 60 psia. Cleaning is done twice a year, mainly in the summer months of May and July. About four man-weeks are required for each cleaning period, restricted to the day shift. The cleaning is done while the equipment is on-line; hence, there is no influence on plant availability.

6.4.4 Freezing Experience

The problem of freezing dominated the discussion at Dunaújváros as it was our first opportunity to review Hungarian experience with indirect dry cooling systems working on the Heller principle.

Contrary to the direct condensing systems (GEA), the medium in the cooling system is single-phased. The flow direction is generally from bottom-to-top and distribution over the individual cooling module tubes seems to be fairly homogenous. This is a result of the circulation pressure being high enough to produce a quasi-forced flow. The origin of the freezing problem appears, therefore, to be caused by influences other than internal hydrodynamics.

Since beginning operation in 1961, about 20 freezing incidents have occurred in Dunaújváros. The incidents were always associated with the shutdown of individual loops, when, due to faulty operation of drain valves and air vents, water was trapped in the modules and then froze. Repair of these tubes did not affect plant availability because all the cooling deltas can be separated from the rest of the loop by appropriate valving. Cost figures for such repairs were not available. The affected tubes are

(a) The air guides have now been removed.

easily identified and repair assistance from the manufacturer is near at hand. Repairs therefore can be made as required. On the average, less than eight hours' labor is needed per freezing incident. These incidents have been getting progressively lower in frequency. The last three years have been free from freezing.

6.4.5 Concluding Remarks

Increasing process steam demands, a defect in the turbine, which reduces power generation to approximately 13 MW, and limited availability of blast furnace gas have compelled the steel works to stop operation of the turbine unit during the past six months. The dry cooling tower has therefore also been taken out of service. The steel plant does not seem to be taking adequate measures to preserve the dry cooling equipment. The possibility of future disintegration of this equipment cannot be excluded.

6.5 DRY COOLING TOWERS OF THE JURIJ GAGARIN POWER PLANT, GYÖNGYÖS, HUNGARY

Date of Visit: September 26, 1975

Participants in the Discussion:

Dipl.-Ing. József Kallós, Power Plant Manager

Dipl.-Ing. Sándor Pal, Manager, Power Plant Thermodynamic Section

Dipl.-Ing. G. Tomacsanyi, HÖTERV (Hungarian Institute for Power Plant Design)

Simhan-BF

6.5.1 General Remarks

Relatively large lignite reserves lie about 120 km northeast of Budapest. These reserves have been exploited in open mines and are the fuel for more than a third of Hungary's installed power production capacity. The power plant installations are situated on the northwestern tip of the lignite fields about 10 km east of the town of Gyöngyös.

Since the power plant went into operation in 1969, five plant sections have been installed, as indicated in Table 6.5-1.

TABLE 6.5-1. Chronology of Plant Section Additions at Gyöngyös, Hungary

Section Number	Capacity (MWe)	Service Date
I	100	1969
II	100	1970
III	220	1971
IV	220	1972
V	220	1973

The very impressive power plant at Gyöngyös has one outstanding feature. Boilers (I/II, 320 t/h each; III/IV/V, 620 t/h each) are open air structures. The turbines are mounted on a common reinforced concrete platform and served by a number of common cranes. The cranes and the platform are also open. The turbines are enclosed in mobile structures, which can be pushed aside to allow access to the turbines. Table 6.5-2 gives the thermodynamic data pertinent to the plant.

TABLE 6.5-2. Gyöngyös Plant Thermodynamic Data

	Plant Section Number			
	I/II	III	IV	V
Boiler	Forced convection with reheat	Forced convection with reheat	Forced convection with reheat	Forced convection with reheat
Boiler rating	2040 psia 1004°F	2040 psia 1060°F	2505 psia 1010°F	2505 psia 1010°F
Steam conditions, turbine inlet	1950 psia 950°F	1950 psia 1050°F	2460 psia 1005°F	2460 psia 1005°F
Turbine rating	100 MW	220 MW	220 MW	220 MW
Heat utilization	8098 Btu/kWh	7790 Btu/kWh	7643 Btu/kWh	7643 Btu/kWh
Cooling system	dry	wet	dry	dry

In the course of planning for Section III, careful analysis showed that adequate makeup water from ground water sources for a wet cooling system of a 200-MW block was available. Hence, Section III was equipped with a wet cooling system with forced draft and glass cascades. Cost figures were generally difficult to obtain. According to plant management, a saving of about 30 percent was achieved as compared with the investment cost for an equivalent dry system. Table 6.5-3 gives the details of the dry cooling system at Gyöngyös.

After commissioning Sections IV and V, plant management has been able to achieve an availability of 88 percent, including the effect of having an average of about 100 MWe capacity shutdown for repair. This availability has not been influenced in any way by the dry cooling systems.

TABLE 6.5-3. Dry Cooling System Data for the Gyöngyös Plant

	Plant Section Number I/II	Plant Section Number IV/V
System	Heller-Forgó indirect condensation	Heller-Forgó indirect condensation
Tower type	Concrete cylindrical shell	Concrete hyperbolic shell
Height	112 m	116 m
Base diameter	53.8 m	109 m
Louvers	yes	yes
Module details		
length	15-m vertical 60° deltas	15-m vertical 60° deltas
tube layers	6 staggered	6 staggered
water flow direction	upward in inner 3 layers, downward in outer 3 layers	upward in inner 3 layers, downward in outer 3 layers
material	aluminum tube, aluminum fin, aluminum spacer ring	aluminum tube, aluminum fin, aluminum spacer ring
	aluminum headers	aluminum headers
corrosion coating	MBV process	MBV process
number of deltas	60	120
number of cooling loops	4	6
heat rejection capacity (design)	476 x 10^6 Btu/h	905 x 10^6 Btu/h
water flow	10,000 m^3/h	22,000 m^3/h
water temperature	inlet 95°F outlet 74°F	inlet 95°F outlet 74°F
design vacuum	94%	94%
design ambient air temperature	55°F	55°F
number of water pumps (motor driver)	2	2
recovery turbines	1	1

6.5.2 Water Quality and Internal Corrosion

The power plant at Gyöngyös is equipped with an extensive and elaborate water treatment unit. Untreated water from ground water sources is pumped out of a reservoir with 8.5×10^6 m^3 capacity over a distance of approximately 3 km to the plant site. The first treatment step removes carbonates (temporary hardness) and the corresponding equipment handles 300 t/h of raw water. A major portion of this water is apparently used as makeup water for the evaporative cooling section. An anion exchanger, a cation exchanger and degassing equipment with 65 t/h capacity complete the water treatment unit. Feed water of the following quality is available:

pH	7.0
O_2	0.02 mg/ℓ
Silicates	0.05 mg/ℓ
Residual hardness	negligible
Fe+++	negligible
Conductivity	0.3 μmho/cm

As with other power plants possessing extensive water treatment units, internal corrosion or fouling has not been observed. This has been corroborated by periodic inspection of modules. No hydrazine or other chemicals are added, which results in the pH stabilizing at about 7.0. This neutral method of operation is an important innovation and its use at Gyöngyös has been successfully demonstrated.

6.5.3 Air-Side Corrosion and Fouling

Personal inspection of all four cooling towers confirmed that the surface quality of the finned tubes of even the oldest cooling tower was unaffected by corrosion. The main maintenance problem results from fouling deposits consisting of dust from the lignite mines, the fuel upgrading unit and dry ash removal unit. The rate of dust deposition depends on wind direction and velocity. During the plant visit, very strong southerly winds blowing at 8-10 m/s swept over the plant. In this wind situation, the Section V cooling tower was taking the major portion of the dust load. However, prevailing winds are generally from the southwest, which affects the towers of Sections I and II. As the design vacuum is rather high (>94 percent), clean air-side surfaces are required. According to plant personnel, cleaning is a year-round job, although it is not performed during winter months. On the average, cleaning requires 1500 man-hours/year for the 100-MWe tower and about 3000 man-hours/year for each 220-MWe tower. Soft low pressure water is used.

6.5.4 Freezing Experience

As reported at Dunaújváros, a major portion of the discussion at Gyöngyös concerned the problem of freezing. Freezing has always been associated with starting up or shutting down individual plant sections. Lignite with a very high sand content is fired in the boilers and the resulting erosion of boiler tubes is very common. The repair of boiler tubes has necessitated repeated shutdown and startup of the units. In the early history of the power plant, there were frequent incidents of freezing. The following remarks were made to elaborate on this problem.

As at Dunaújváros, improper opening and closing of drain valves as well as air vents led to trapping of water in the cooling tubes. These remotely-operated devices were originally designed with electro-hydraulic mechanisms. Due to the change in the viscosity of the hydraulic fluid as a function of the low ambient temperature, their operational characteristics either changed markedly or they just got stuck. All these components in the first two towers have been replaced with electromechanical devices. Because the guarantees on the original equipment had lapsed, the costs for the repair and replacement of valves were paid by the plant operators. The other two towers were equipped from the beginning with electromechanical devices.

The module length of 15 m is relatively high. As an innovation, the header at the top of the module served merely as a collector before the water changed flow direction. Two headers at the bottom, one as inlet and the other as outlet, were also new design elements. Resulting from the unusually long tubes, drainage and necessary venting had to be mutually adjusted. In the new towers, the headers at the bottom of the modules have an auxiliary vent tube to facilitate venting. This tube is electrically heated to assure that freezing does not block the venting action.

Repeated opening and closing of the valves and vents caused unusual gasket wear. These had to be replaced with gaskets made of more durable material.

Tanks inside the base area of the towers generally have a holding capacity equal to 75 percent of the contents of cooling system. The other 25 percent can be accommodated in the condenser. Before starting up, care is taken that the water in the cooling system is sufficiently warm.

Despite the numerous freezing incidents, forced outage of the plant has never been caused by the dry cooling equipment.

6.5.5 Wind Effects

Recirculation is no problem at Gyöngyös. However, wind effects have been noticed. Joint efforts of plant management, HÖTERV and the Technische Hochschule, Zürich, are now underway to define and solve the problem. The university team from Switzerland was taking field measurements during this plant visit. The cooling towers, which are slightly over 100 m high, dominate the otherwise level landscape. Full wind velocity develops very quickly, i.e., the Prandtl layer thickness should correspond roughly to the tower height. It is felt that tower draft reduces with strong winds. The investigations in progress should be able to define this problem more precisely.

6.5.6 Concluding Remarks

The power plant at Gyöngyös is an impressive example of technical achievement and demonstrates in a striking manner the possibilities of dry cooling in power plants with giant capacities. Additional published information is contained in Reference 17.

6.6 DRY COOLING EQUIPMENT AT THE ARBED-STEELWORKS IN DUDELANGE, LUXEMBOURG

Date of Visit: September 29, 1975

Participants in the Discussion:

Dipl.-Ing. Sturm, Power Plant Manager

Simhan-BF

6.6.1 General Remarks

ARBED is a leading steel manufacturer and produces about 2 million tons per year at the Dudelange plant in southern Luxembourg near the French border. The dry cooling installation is part of the power plant which provides 50 percent of the steelworks' energy requirement. Until about 1965 this steelwork was connected to a local energy grid with a neighboring ARBED steel plant. In this period both plants produced electricity at a frequency of 42.5 Hz. Increasing energy requirements caused both plants to join the national electricity grid. When this occurred, the speed of the generator was altered to provide a generating frequency of 50 Hz.

Blast furnace gas is the basic fuel at this power plant. In 1965 the boiler was modified to burn crude oil because blast furnace gas, also used to fuel gas turbine-driven air compressors, was getting scarce as compressed air demands increased.

At design conditions, 50 t/h of steam from the turbine are condensed directly in a GEA dry cooling system. Loads change rapidly, however, within the range of 8-14 MW because of changing demand in the rolling mills. To meet changing loads steam is tapped from a Roote's steam reservoir at a pressure of 240 psia. With the exception of a small brook with inadequate water capacity, the only water at the plant site is in several small ponds used to cool water from blast furnaces. Dry cooling is therefore required for the turbine exhaust steam.

Table 6.6-1 gives the details of the dry cooling system together with pertinent data regarding thermodynamics of the power plant.

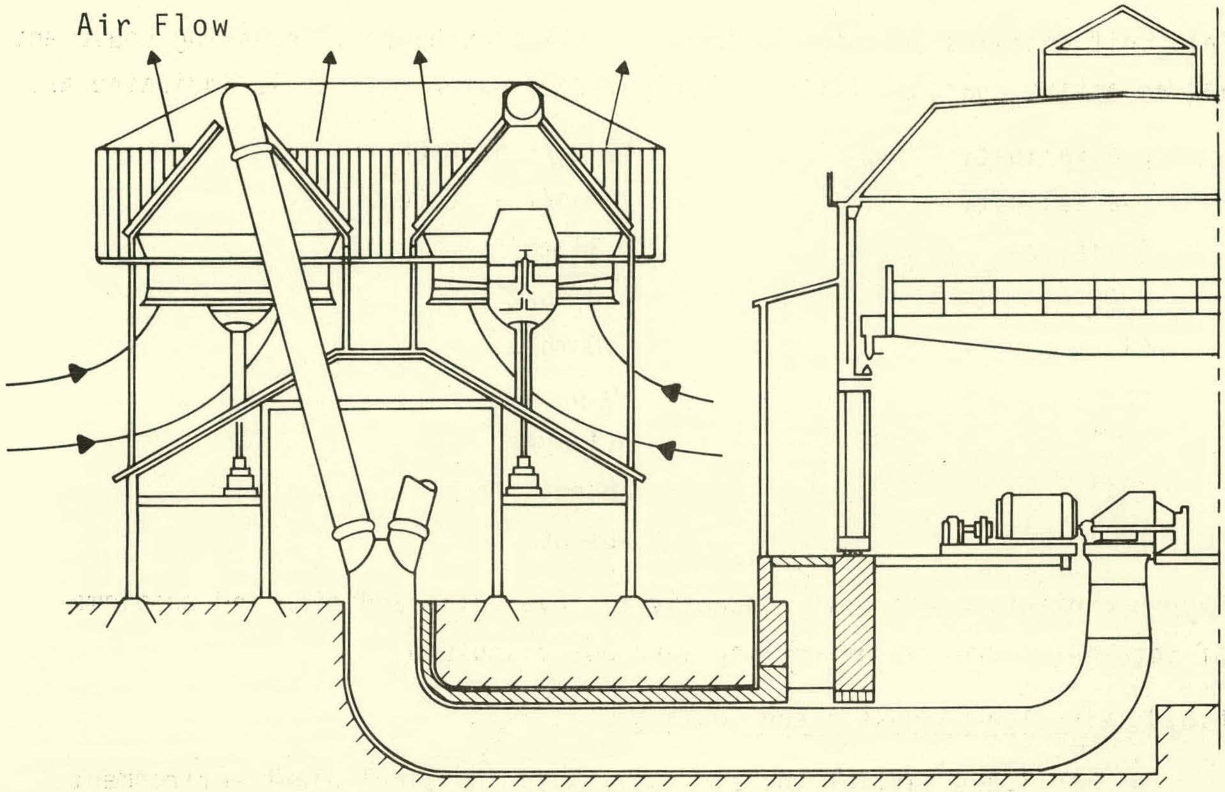
TABLE 6.6-1. ARBED-Steelworks Dry Cooling Equipment Data

Boiler:	natural circulation, fueled by blast furnace gas and crude oil
Rating:	65 t/h at 825 psia and 880°F
Turbine:	14 MWe with multistage bleeding
Dry cooling system:	GEA direct condensing with forced draft
First operation:	1956
Tube/fin specification:	round copper tubes with wound copper fins
Tube arrangement:	45° delta, three layer staggered
Tube length:	4.5 m
Design steam vacuum:	0.075 ata (92.5 percent)
Steam flow (design):	50 t/h
Heat rejection:	110 x 10^6 Btu/h
Ambient air temperature:	55°F
Number of fans:	8
Diameter:	5000 mm
Maximum fan speed:	170 rpm
Speed regulation:	2 speed with pole variation
Total fan power:	372 KWe

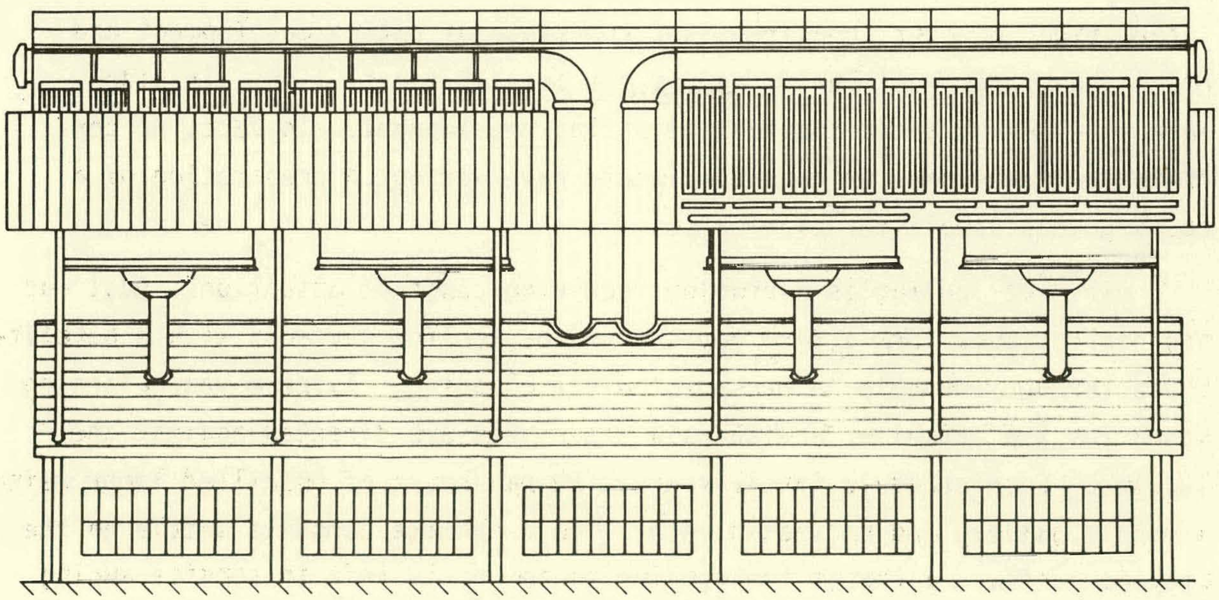
The dry cooling installation is supported by a steel structure over the roof of a workshop building. The fans are driven by vertical shafts. The change in drive direction between the motor axis and the fan shaft takes place in the bevel gear box. The steam line from the turbine is bifurcated into four feed lines corresponding to the four deltas. Each delta has 16 modules, all with a top to bottom steam flow. The installation is in the immediate vicinity of the blast furnaces which generate very heavy dust loads. Arrangement of the plant is shown in Figure 6.6-1.

6.6.2 Water Quality and Internal Corrosion

Although the power plant is equipped with a natural circulation boiler, the water quality is maintained at standards required by forced circulation boilers by a well-equipped medium capacity water treatment unit.



(a) End View Section



(b) Side View

FIGURE 6.6-1. Dry Cooling Tower Arrangement at Dudelange

This unit contains an anion exchanger, cation exchanger, degassing equipment and an active charcoal filter. Typical feed water quality is indicated as:

p-alkalinity	14 mg/ℓ as $CaCO_3$
m-alkalinity	26 mg/ℓ as $CaCO_3$
Silicates	1.34 mg/ℓ
P_2O_5	1.0 mg/ℓ
Cl^-	<1.0 mg/ℓ
pH	10.4
NH_4^+	0.1 mg/ℓ
Cu^{++}	absent
FE^{+++}	absent

Oxygen content, electrical conductivity, hydrazine addition and problems of internal corrosion or fouling were not discussed.

6.6.3 Air-Side Corrosion and Fouling

As mentioned earlier the air quality in the steel plant environment is bad. Excessive dust loads and high SO_2 concentrations are normal. It was therefore not surprising that the cooling tubes were covered with a patina which made visual recognition of the tube material difficult. Plant information, however, confirms that the state of patina development had reached a static equilibrium during the last 15 years, i.e., air-side corrosion ceased after the initial patina development. In fact, no corrosion problems have arisen which would have warranted preparation of a cooling tube sample for examination.

Air-side fouling is a problem requiring constant attention. Dust and organic residues form a firm deposit on the cooling surfaces with a bakelite character not amenable to pressurized air cleaning. Twice a year cleaning schedules are organized and 90-psia water jets are directed against the modules. Each schedule involves about 80 man-hours of unskilled labor using a mobile gallery and untreated water. No carbonate deposits settle on the cooling surfaces although the cooling equipment is left in service during the cleaning operation. Only the fan of the module being cleaned is switched off.

6.6.4 Freezing Experience

No freezing incidents have been recorded. Control instrumentation in the cooling equipment assures that the condensate temperature does not fall below 40°F. To achieve this result, a careful strategy of fan speed regulation, including control of the number of fans in operation, has been developed. Under extreme conditions, tarpaulin sheets are spread over the deltas and recirculation is then encouraged.

6.6.5 Maintenance

This was one of the few plants observed using preventive maintenance. All eight gear boxes and the corresponding motors are overhauled once a year. The gear box to be overhauled is replaced with a previously reconditioned spare unit on a unit rotation basis. Separate cost figures for this maintenance cannot be estimated because the routine maintenance team is part of plant personnel. According to information available, about 80 man-hours are required to overhaul a gear box. This work is generally done in the winter months.

6.6.6 Concluding Remarks

The dry cooling equipment at Dudelange has almost no operation or maintenance problems.

6.7 DRY COOLING EQUIPMENT IN THE INDUSTRIAL POWER PLANT OF THE BASF CHEMICAL WORKS, LUDWIGSHAFEN, GERMANY

Date of Visit: September 30, 1975

Participants in the Discussion:

Ober-Ing. Dr. K. Müller, Manager Energy Department

Ing. Hanbold

Ing. Gert

Simhan-BF

6.7.1 General Remarks

The design philosophy for the industrial power plant at Ludwigshafen is characteristic of a giant chemical plant. Process steam production and power generation have equal priority. Thermodynamic design is optimized to favor requirements for the provision of process steam and electric power generation must meet limits set by process engineering. The full thermodynamic layout of the BASF power plant is very complicated and only those details pertinent to the present discussion will be given. The total installed steam capacity at BASF is 1060 t/h and is operated by four oil-fired forced convection boilers. The process steam grid supplies steam at the following pressures of 1800, 205, 67.5 and 38 psia. Two boilers rated at 265 t/h, 3150 psia and 1005°F with reheating, form the backbone of the power supply and feed two back pressure turbines with bleeds at the pressure levels mentioned above. Exhaust steam from both back pressure turbines feed a condensing turbine at a pressure of 270 psia with slight superheat. This turbine, which is also bled to supply diverse feed water heaters, discharges 50 t/h of steam at 95 percent vacuum to the dry cooling equipment. The condensing turbine produces 39 MW of electric power. The back pressure turbines satisfy the base power load and the condensing turbine is justified by its ability to produce peaking power when process steam demands are low and the surplus steam capacity associated with optimal boiler operation is available. The condensing turbine, in operation since 1967, cost approximately 6 x 10^6 DM. The total cost of dry cooling equipment was about 1.1 x 10^6 DM in 1967.

The dry cooling equipment is mounted on the same steel structure which carries the galleries around the open air boilers. The power plant is situated in the center of the chemical works. The environment can be classified as industrial with dust loads and SO_2 concentrations characteristic of a chemical plant. The cooling modules are arranged in the form of two parallel deltas in the conventional GEA arrangement. The dry cooling equipment is not provided with louvers. No wind shields are erected around the cooling deltas. Table 6.7-1 gives the details of the dry cooling equipment.

TABLE 6.7-1. BASF Chemical Works Dry Cooling Equipment Features

Type of cooling system:	GEA direct condensing
Air flow:	forced draft
Tube arrangement:	60° deltas, 2 deltas in parallel
Tube length	3.7 m
Tube layers	3 staggered
Tube/fin specifications:	galvanized elliptic steel tube, steel fin
Modules:	12 modules/delta, 8 modules parallel-flow, 4 modules counterflow
Vacuum:	0.055 ata (94.5 percent)
Steam flow:	50 t/h
Design heat rejection capacity:	112×10^6 Btu/h
Ambient air temperature:	50°F
Number of fans:	8
Diameter:	2.45 m
Maximum fan speed	196 rpm (2 speed with pole variation)

It is interesting to note that most of the steam produced in the power plant is ultimately condensed in process heaters by direct mixing. Compared to the steam handled in the process heaters, the steam capacity of the dry cooling system is small. More than 500 t/h of water is consumed in open processes and must be replenished after appropriate water treatment to keep the process steam grid going. Both these factors prompted the provocative question about the rationale for the choice of dry direct cooling for the condensing turbine. Two reasons were advanced. First, plant restrictions did not allow the siting of a wet cooling system in the vicinity of the power plant. Second, the maintenance cost of a wet system could be substantial with fully treated makeup water.

6.7.2 Water Quality and Internal Corrosion

As already mentioned, the BASF chemical plant incorporates an extensive water treatment unit, which in itself is administered as an individual department of the central services. The power plant draws required water from this central unit. Details of a typical analysis of the condensate are given below.

pH	9.5
conductivity	0.15 μmho/cm
oxidizable residual (equivalent $KMnO_4$)	0.5 mg/ℓ $KMnO_4$
total carbon content	0.2 mg/ℓ
p-alkalinity	5 mg/ℓ as $CaCO_3$
total residual hardness	negligible
O_2	0.005 mg/ℓ
Hydrazine	0.002 mg/ℓ
Fe^{+++}	0.003 mg/ℓ
Cu^{++}	0.001 mg/ℓ
Na^{+}	0.001 mg/ℓ
NH_4^{+}	2 mg/ℓ
Cl^{-}	0.02 mg/ℓ
Silicates	0.01 mg/ℓ

As one of the leading chemical manufacturers, BASF has an immense knowledge of corrosion problems. Periodic inspection of various kinds of tubing material under varying operating conditions guaranteed that no corrosion or internal fouling has taken place in boiler, turbine or dry cooling components. The dry cooling installation has never been completely out of service for a period longer than 2 weeks which occurs during plant inspection every 6000 hours. As a precaution against internal corrosion, the dry cooling equipment is kept under vacuum during these periods.

6.7.3 Air-Side Corrosion and Fouling

Visual inspection showed that the galvanized coating of the finned tubes was getting rusty in randomly distributed patches. According to plant information, the quality of galvanization was adequate and the existing degree of corrosion could be considered to be in a state of equilibrium. The degree of corrosion attained was considered to be the intrinsic minimum under prevailing environmental conditions. These statements were admittedly subjective. No quantitative investigations have been conducted with respect to this issue.

Air-side fouling must be fought almost year-round. The deposit on the cooling surface is mainly dust which bakes together with organic matter, yielding a comparatively dense matty film. Cleaning is carried out four times a year with emphasis on the warmer months. Regular unskilled shift personnel carry out this assignment. Originally, very high pressure (225 psia) untreated water jets were used, but this was detrimental to the fins. Subsequently, the same cleaning effect was found to be achievable with much lower pressures (90 psia) and without damage to fins. During the cleaning, only the fans of the module involved are switched off. The necessity for cleaning is indicated by a marked (10 to 20 percent) increase in the pressure difference which must be generated by the fans. According to plant experience, a good deal of the dust load is swept into the interstices of the modules by the induced secondary flow otherwise known as recirculation.

In the course of the discussion, plant management advanced the opinion that the fin spacing was rather small. In spite of the effort needed to manage air-side fouling, the choice of dry cooling equipment has not been regretted and the choice of future installations would not be prejudiced by this experience.

6.7.4 Freezing Experience

Close contact between plant management and GEA has existed since the planning stage, and a careful strategy has been worked out to prevent freezing incidents. Temperatures of the condenser header modules are displayed on the central control panel together with inlet and outlet air temperatures. Speed regulation and control of the number of fans in operation allow operation without freezing. Freezing incidents have not been reported.

6.7.5 Concluding Remarks

In the initial stages, considerable trouble was experienced with a repeated breakdown of gear box bearings. Apparently, unexpected vibrations caused these breakdowns. BASF plant investigation with GEA assistance has now solved the problem. A spare gear box is kept on hand to replace a faulty gear box, which is then repaired and becomes the spare unit. This maintenance is not budgeted and requires a two-man shift when necessary. A regular team is responsible for unit repairs and more labor can be called in at short notice.

Power plant availability is considered to be high at 97 percent and the dry cooling equipment does not influence plant availability.

6.8 DRY COOLING EQUIPMENT AT THE ESSO REFINERY IN PORT JERÓME, FRANCE

Date of Visit: October 1, 1975

Participants in the Discussion:

Ing. Ganser

Ing. Jau

Simhan-BF

6.8.1 General Remarks

Esso Chimie is a subsidiary of Esso France, which specializes in the refinement and synthesis of basic organic compounds required in the chemical industry. An Esso automotive fuel refinery is located nearby. Both plants are situated in Notre Dame de Gravenchon, a small town on the Seine about 30 km upriver from Le Havre. The northern bank of this particular section of the Seine in Normandy is the center of a newly developing and rapidly expanding petrochemical industry.

The dry cooling equipment at Port Jeróme serves the works' power plant. The natural circulation boiler supplies 280 t/h of steam at 1275 psia and 850°F. Process steam is bled from two turbines, which produce the major part (35 MWe) of the total electric power output. A smaller condensing turbine is apparently used for electric power needs only. All three turbines exhaust into corresponding GEA air cooled condensers. The condenser units are arranged in parallel deltas. The turbines have different heat rejection requirements and hence, the number of modules in each of the three independent dry cooling subsystems has been suited to the corresponding heat load.

The close proximity of the river Seine is not a source of cooling water and no other water sources such as ground water are sufficient to supply wet cooling systems. Up to 90 percent of the cooling load of this plant is met by the dry cooling equipment. The remaining 10 percent of the cooling load is handled by evaporative cooling equipment, because of process control limitations. The following water cost details are noteworthy:

Untreated water	60 NF/1000 m^3
Treated water (negligible residual hardness)	640 NF/1000 m^3
Fully-treated water	780 NF/1000 m^3

A central water treatment department is responsible for monitoring and maintaining the water quality for the entire plant.

Although approximately 50 percent of the steam serves as process steam, the plant production is apparently relatively constant. Therefore the variation in turbine loading and subsequent demands on the dry cooling equipment vary only as much as 5 percent, regardless of the season. Details of the dry cooling equipment are shown in Table 6.8-1.

The five deltas of the dry cooling equipment are built on a common platform approximately 10 m above ground level (Figure 6.8-1). The platform and supporting pillar system are reinforced concrete structures. The entire works complex, including boiler house, machine house, and dry cooling equipment, faces westerly winds which follow the upstream direction of the Seine River valley.

6.8.2 Water Quality and Internal Corrosion

Water analysis for the Port Jerôme plant is conducted only once each week. Because the plant's water quality is maintained by the neighboring refinery, available data on condensate quality were limited to that listed below.

Conductivity	0.5 μmho/cm
pH	7.5
Phosphates	negligible
Silicates	0.02 mg/ℓ
Na^+	0.01 mg/ℓ
Residual hardness	negligible
O_2	0.2 mg/ℓ

Internal corrosion or fouling has not been observed. It is interesting to note that, during downtime, the condensate is drained from the dry cooling

TABLE 6.8-1. Port Jeróme Refinery Dry Cooling Equipment Details

Year of Commission:	1967		
Type of dry cooling equipment:	GEA direct condensing with forced draft		
Tube/fin:	aluminum elliptical tube and fin (apparently corresponding to ASTM A 214. The method of thermal connection between fins and tubes is uncertain, as are the tube dimensions)		
Tube arrangement:	53° delta		
Tube length:	6.3 m		
Tube layers:	3 staggered		
	Subsystem		
	I	II	III
Number of deltas:	2 parallel	2 parallel	1
Number of modules:	32/delta	32/delta	32/delta
Number of condenser modules:	24/delta	24/delta	10/delta
Number of Dephlagmator modules:	8/delta	8/delta	2/delta
Design heat rejection capacity:	158×10^6 Btu/h	193×10^6 Btu/h	31×10^6 Btu/h
Vacuum:	80 percent	80 percent	80 percent
Exhaust steam temperature:	140°F	140°F	140°F
Steam mass flow:	71 t/h	86 t/h	14/t/h
Number of fans:	6/delta	6/delta	2/delta
Speed variation:	2 steps	2 steps	2 steps
Louvers:	no	no	no
Wind Shields:	no	no	no
Total fan power:		1170 kWe	

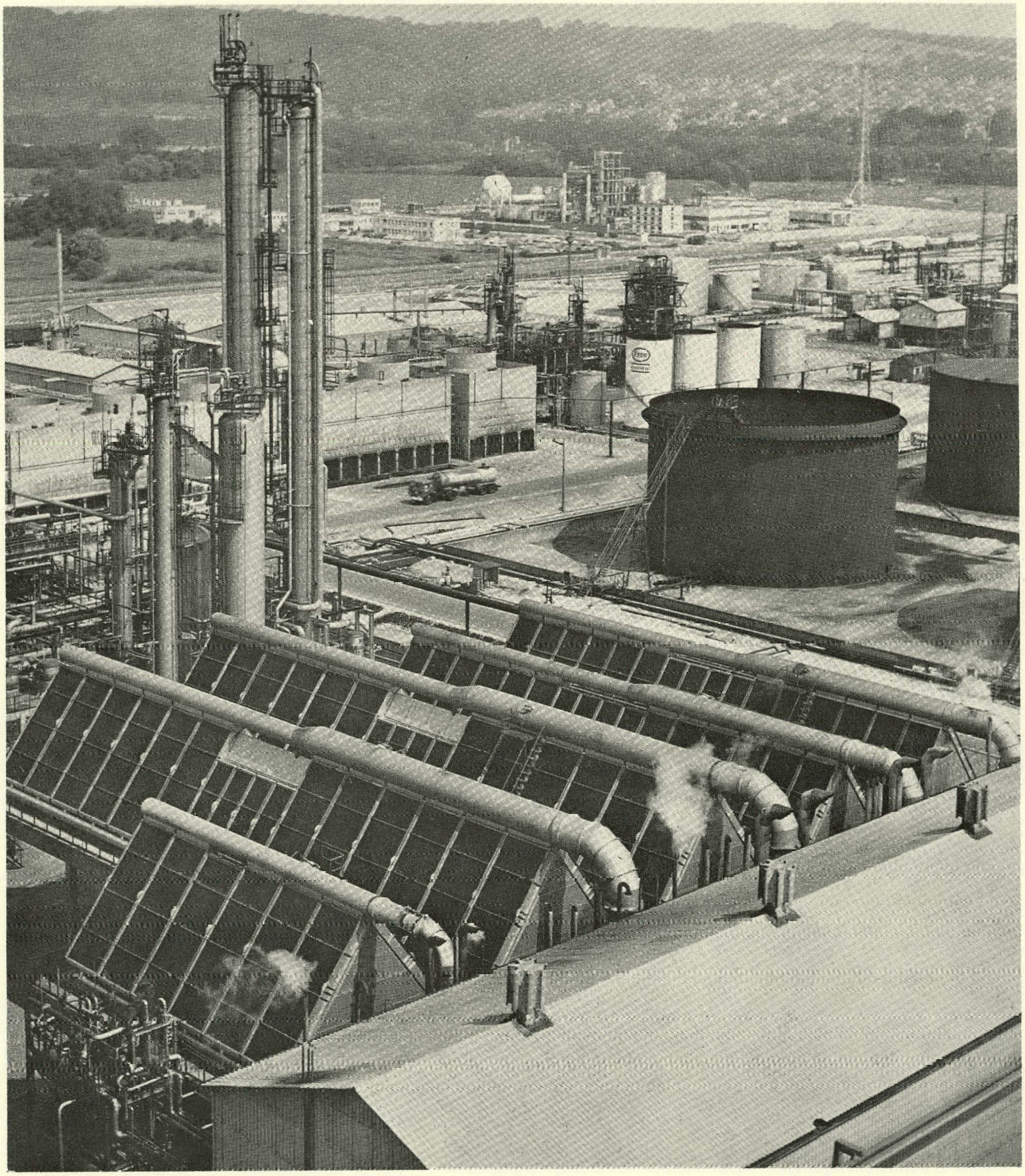


FIGURE 6.8-1. Port Jerôme Plant

equipment, which is then filled with a corrosion-inhibiting fluid apparently very prevalent in the petrochemical industry. The type and properties of this fluid were not discussed and it was also difficult to ascertain how this fluid is removed from the equipment without leaving traces when the equipment goes on line again. This was a result of language difficulties. The cost of the treatment was also not available.

6.8.3 Air-Side Corrosion and Fouling

Considerable air-side corrosion at Port Jerôme is apparent. Rather moist air from the English Channel blows up the Seine valley and the SO_2 concentration resulting from this plant and from the neighborhood is rather high. These two factors may be responsible for the observed state of corrosion. It should be noted, however, that plant management does not consider the problem of corrosion serious. No performance penalties have been noticed to date.

As with the other petrochemical plants, a thin (approximately 0.25 to 0.5 mm) deposit of organic material was noticed especially in the tip areas of the fins. This deposit bakes itself firmly to the air-side surface and is not amenable to normal cleaning procedures. The origin of the organic material is attributed to the cracking and refining columns which emit polymers.

Regular cleaning campaigns twice a year are necessary to keep fouling on the air-side surfaces to a minimum. For all three units, a total of some 400 man-hours are required. Water jets and subsequent steam jets are directed against the cooling tubes in the direction of air flow through the modules.

6.8.4 Maintenance and Repair

Maintenance involving the renewal of lubricating oil in fans and gear boxes and semiannual cleaning requires a total of 700 man-hours/yr. No additional preventive maintenance is planned. Spare parts are available to replace random components which fail. Defective components are generally replaced with the spares without shutting down the plant. The repair of components, including dismantling and refitting, requires an average of about 200 man-hours/yr. A three-shift maintenance team is available at the plant.

6.8.5 Freezing Experience

The ambient air temperature at Port Jeróme does not usually fall below freezing. On the average, only two 24-hour periods with temperatures as low as 28°F occur in a year. A careful control strategy, coupled with the rather high steam temperatures, has prevented freezing incidents so far.

6.8.6 Concluding Remarks

Recirculation effects have been noticed and investigations are underway. It is believed that the ground clearance of 12 m (two fan diameters) and the absence of wind shields aggravate this problem. Remedial action will be taken after the results of the investigations are known.

6.9 DRY COOLING EQUIPMENT AT THE WASTE-BURNING PLANT, CITY OF BREMEN, GERMANY

Date of Visit: October 3, 1975
Participants in the Discussion:
Ing. Hinz, Plant Manager
Simhan-BF

6.9.1 General Remarks

For years, burning was considered the most suitable way to dispose of domestic wastes. Recent debate on other means of waste disposal, such as composition, have taken place, and waste burning plants are becoming unpopular. The plant at Bremen (Figure 6.9-1) was planned and erected during the heyday of waste-burning and handles almost all the domestic wastes (200,000 t/year) of the federal state of Bremen in a round-the-clock operation. The most remarkable feature of the Bremen plant is that, contrary to usual waste-burning practice, no utilization of the heat released was ever planned; the entire steam produced in the waste-burning boilers was proposed to be condensed in the dry cooling equipment, after allowing for consumption in the turbines which drive the feed water pump and fans of the cooling equipment. In the meantime, the recent establishment of the University of Bremen in 1972, which is situated in very close proximity to the plant, is supplied with net plant steam output during the winter months.

The plant is situated in a residential area with a park-like character. Apart from the general scarcity of cooling water, the planners wanted to avoid moisture plumes at all costs. Therefore, dry cooling systems were chosen, which, despite investments amounting to 70 percent more than those for an equivalent evaporative system, do not require running expenses for makeup water. It should also be noted that city regulations limit the dust emissions to 150 mg/Nm^3 of air.

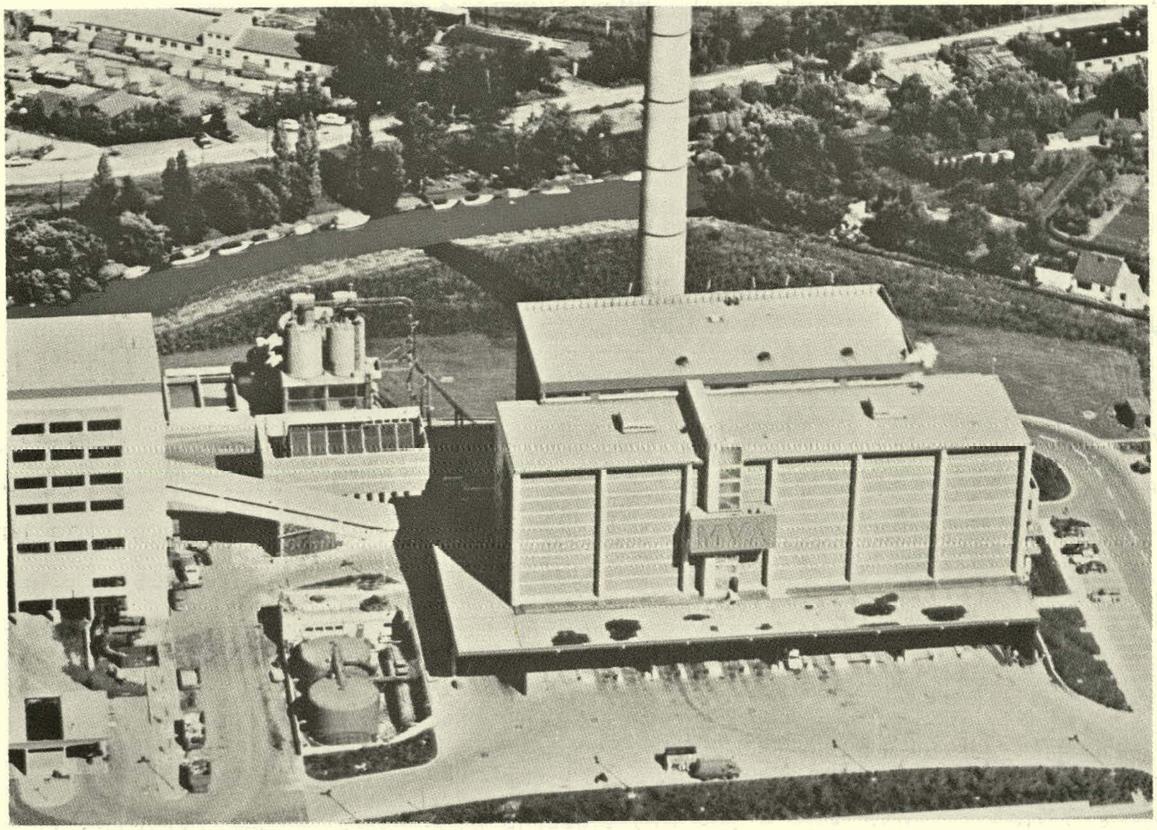


FIGURE 6.9-1. Bremen Waste-Burning Plant and Attached Dry Cooling Equipment

Characteristic data of the Bremen waste-burning plant and attached dry cooling equipment are as follows:

Waste burning boiler steam capacity:	3 x 40 t/h
Steam conditions:	saturated at 330 psia and 420°F
Steam consumption:	28 t/h at 330 psia and 420°F for 7 turbines discharging exhaust steam at 35 psia. One 120-kW turbine for the feed pump. One 270-kW turbine for the fans attached to the dry cooling equipment.

Exhaust steam from the turbines is fed into the low pressure section of the dry condenser at a pressure of 35 psia. The dry cooling equipment is exceptional since it consists of two sections, a high pressure section, and a low pressure section. Both sections have the same module geometry and are accommodated in a single delta which rests on a platform about 10 m above the ground on a pillar system. The platform and the pillar system form a unified reinforced concrete structure. The turbines which drive the fans rest on foundations on the floor area within the perimeter of the pillar system. To fulfill stringent residential noise level regulations, baffle walls have been erected which acoustically screen the space below the platform from the environment.

In the dry cooling equipment, the inlet pressure of steam is about 240 psia in the high pressure section and about 35 psia in the low pressure section. Both sections are finally depressurized to a common outlet pressure of approximately 5 psia. The details of the dry cooling system are listed in Table 6.9-1. Since the University has been occupied, the load on the dry cooling equipment during winter week days is almost negligible. The load rises to the design value on winter weekends and during the summer.

6.9.2 Water Quality and Internal Corrosion

For natural circulation boilers with a relatively low specific heat release to the radiant heat exchanger surfaces, a relatively simple water treatment unit has been installed. About 90 t/day of makeup water must be processed. One laboratory assistant is in charge of the unit and performs an analysis once a day. Hydrazine is added to control oxygen content. A typical condensate analysis is:

pH	10.9
phosphates	10 mg/ℓ
hydrazine	0.4 mg/ℓ
Fe^{+++}	0.26 mg/ℓ
Cu^{++}	0.013 mg/ℓ
silicates	34.6 mg/ℓ
p-alkalinity	100 mg/ℓ as $CaCO_3$
m-alkalinity	130 mg/ℓ as $CaCO_3$
residual hardness	negligible

TABLE 6.9-1. City of Bremen Waste-Burning Plant Dry Cooling Equipment Details

Year of commission:	1968	
Dry Cooling equipment:	GEA direct condensing with forced draft	
Material:	galvanized circular steel tube 30 mm OD with 10 mm steel fins broad wound, at 11 fins/in.	
Tube arrangement:	60° delta	
Tube length:	9.6 m	
Tube layers	3 staggered	
Design ambient air temperature:	68°F	
Sections:	high pressure	low pressure
Number of modules:	8	8
Number of condenser modules:	8	6
Number of Dephlagmator modules:	-	-
Design heat rejection capacity:	182.6×10^6 Btu/h	62.4×10^6 Btu/h
Steam mass flow:	82 t/h	28 t/h
Number of fans (turbine driven):	6	
Fan diameter:	3.55 m	
Fan speed:	322 rpm	
Total fan power:	210 kW	
Air flow regulation:	variation of fan blade angle (set with fan at rest), limited range variable speed	
Louvers:	none	
Wind shield:	yes	

In the initial stages of plant life, internal corrosion was observed, especially in the boiler region where two-phase flow existed. Addition of Livoxin has stopped this corrosion. Apart from this incident, no internal corrosion has been observed. Careful scrutiny during annual maintenance (2 weeks during the summer) is devoted to this problem.

6.9.3 Air-Side Corrosion and Fouling

The environment around the plant at Bremen corresponds to that of an urban green residential area. No air-side corrosion has been observed to date.

In addition to the acoustic baffles, the cooling delta is enclosed by a relatively high wind shield. These two factors might explain the surprising fact that, during the last 7 years of operation, no fouling has taken place and no cleaning operation has been required.

6.9.4 Freezing Experience

Freezing incidents were encountered only in the first winter of operation. This can be attributed to inadequate experience of the plant operating personnel. Intensive training strategies for freezing weather have been conducted since then. The valves leading to and from the equipment, as well as the drain valves and air vents, have been replaced by remotely operated devices.

6.9.5 Maintenance

A regular 2-week preventive maintenance stoppage is planned every year. All gear box lubricating oil is renewed twice a year. No serious failures resulting in plant shutdown have been reported.

6.9.6 Codes and Standards

Stringent regulations pertinent to air quality and noise emission have had to be met because the plant is sited in a predominantly residential area.

6.9.7 Concluding Remarks

Atmospheric effects and especially recirculation effects have not been observed. The plant cost DM 45 x 10^6 in 1967-1968. The sale of scrap and slag material for construction purposes was adequate to pay for personnel and running costs. The utilization of heat has now opened up the possibility of earnings on the capital investment.

6.10 DRY COOLING EQUIPMENT AT THE BENZENE REFINERY REDESTILLATIONS-GEMEINSCHAFT, GELSENKIRCHEN, GERMANY

Date of Visit: October 7, 1975

Participants in the Discussion:

Dr. Treffny, Director

Dr. Braun, Deputy Director

Simhan-BF

6.10.1 General Remarks

The plant at Gelsenkirchen was selected for assessment for one main reason. This was the only plant which, according to the equipment survey in Phase I, dealt with the condensation of a nearly pure single phase, single component, organic vapor (benzene) in dry cooling equipment. Moreover, the design heat rejection capacity and the merit index were high enough to justify inclusion. The quality of the discussion, and the fact that this plant offers the possibility of a comparison between wet cooling equipment and dry cooling equipment designed to accomplish identical thermodynamic tasks have amply justified the choice.

This plant is a joint venture of a voluntary union of all West German cokeries for the redistillation of the impure benzene output of these cokeries. The benzene is a fraction of the condensate of the volatiles driven out during the coking process. Redistillation of the impure benzene, which reaches the plant via a pipeline grid in liquid form, produces pure benzene (99.6 percent purity guaranteed) which is pumped through a pipeline to the chemical plant at Marl-Hüls where it is used as a base for further synthesis. The whole process is automated.

The dry cooling equipment reviewed here condenses the redistilled benzene vapor. Saturation temperatures vary between 95°F and 160°F and correspond to the temperature variation of the ambient air. As air flow rate through the dry cooling equipment is kept nearly constant, saturation conditions in the condenser are a function of cooling air parameters. To compensate these variations, a varying fraction of the condensate leaving the condenser is subcooled. By the mixing of the hot condensate with the subcooled fraction, a subcooled condensate of constant temperature is obtained. The heat exchanger equipment for subcooling is also a dry system and the corresponding modules have been accommodated in the condenser deltas.

Significant data describing the dry cooling equipment are given in Table 6.10-1.

TABLE 6.10-1. Gelsenkirchen Plant Dry Cooling Equipment Details

Year of commission:	1957
Type of cooling equipment:	GEA direct condensing with forced draft
Medium condensed:	benzene
Material:	galvanized elliptical steel tube with steel fins
Tube length:	6 m
Tube arrangement:	2 deltas on different structures,[a] in the form of an isosceles triangle with 55° base angle
Tube layers:	3 staggered
Number of modules:	20/delta
Number of condenser modules:	20/delta
Number of Dephlagmator modules:	--
Heat rejection capacity:	40×10^6 Btu/h/delta
Design mass flow of condensing vapor:	125 t/h
Design vapor conditions:	15 psia at 130°F
Ambient air temperature:	60°F
Number of fans:	2/delta
Fan diameter:	4.7 m
Fan speed:	142 rpm, two speeds with pole variation
Fan power:	28 kW/fan
Louvers:	none
Wind shields:	none

(a) In 1962 the output of the impure benzene doubled, as did the demand for the pure redistilled condensate. Hence, in addition to the cooling equipment commissioned in 1957, a second identical unit was then put into operation. This unit, with its delta axis running in the NW-SE direction, was placed perpendicular to the existing unit.

6.10.2 Internal Corrosion and Fouling

The condensing benzene vapors inevitably carry water vapor and water droplets with a total mass fraction of 0.05. This water in conjunction with residual sulfur derivates can result in very serious internal corrosion. Residual ammonia compounds together with chlorine compounds also hydrolyze in the course of complicated chemical chain reactions. The ammonia chloride (NH_4Cl) formed is also reported to cause internal corrosion including pitting and progressive reduction in wall thickness. These two corrosion mechanisms, which are well known, have been rendered ineffective at Gelsenkirchen by the application of an internal corrosion-resistant paint, thermally hardened at 220°F. This coating was applied after galvanization. Currently, this internal coating is being replaced with special PVC-material sprayed on. Internal fouling has been a serious problem and the deposits, although now stable, have reduced the heat exchange capacity to about 65 percent of the design value. By coincidence the demand for benzene has also decreased correspondingly and therefore plant output is satisfactory.

6.10.3 External Corrosion

Significant deterioration of the galvanizing layer has taken place in the last 18 years of operation as a result of the generally poor air quality in the industrial environment around the plant. Investigations have shown local corrosion of about 75 percent of the original 50 μm zinc layer. Air-side corrosion in the subcooling heat exchanger is more severe than in the condenser. This is attributed to the relatively lower operating temperatures. However, external corrosion has not limited the cooling function or operation of the plant.

6.10.4 Air-Side Fouling

Air-side surfaces require cleaning 3 times a year. The deposit on the surfaces and in the fin interstices is mainly coal dust and soot. Deposits grow up to an equilibrium thickness. The state of equilibrium may be attributed to the fact that, with growing thickness, the local air velocity in the interstices also increases to a point where further settling of material is discouraged. Treated water with a total head of about 750 psia is used for spraying. Two nozzle forms have been developed. One is a converging nozzle of circular cross section. The other is a nozzle with a narrow rectangular exit cross section developed from a circular cross section. The deltas are equipped with moving galleries to facilitate the cleaning operation. Each cleaning operation involves a total of four man-days and is carried out routinely by unskilled shift personnel.

6.10.5 Freezing Experience

Freezing of benzene in the cooling tubes is a nuisance rather than a calamity because benzene contracts upon freezing. However, the tubes become blocked. This problem was common in the early life of the plant, especially during equipment startup and shutdown in extremely cold winters. Temperature sensors have now been mounted to measure air temperature, and, during freezing weather, corresponding strategies can then be adopted. These include fan speed regulation, periodic switching-in of fans and ultimately covering up the air-side surfaces with sheet metal screens.

6.10.6 Repair and Maintenance

In the last 18 years major repairs have been necessary only twice and were associated with gear box damage. The repair, including dismantling and refitting, requires about nine man-days. Apart from these two incidents which caused a 50 percent decrease in benzene output, no other trouble has been experienced.

Preventive maintenance is part of the routine work of day shift personnel. A major overhaul is carried out once every 4 years. This extends over a maximum period of 3 weeks, which is strictly scheduled. No cost figures are available.

6.10.7 Wind and Recirculation Effects

The first unit was markedly influenced by wind velocity and wind direction. Since the erection of the second unit with a siting geometry perpendicular to that of the first, these influences have been reduced to a minimum.

Recirculation effects are also absent on these units. The deltas rest on a massive concrete platform supported by concrete pillars. The fans with integrated motors and gear boxes are also supported by the platform. The subcooling equipment in the form of vertical modules occupies the long sides of the rectangle formed by the pillar structure, providing longitudinal walls half the height of the deltas. This arrangement could be reason for the absence of recirculation effects.

6.10.8 Codes and Standards

Process equipment for pressures $\leq$ 10 psia are not governed by any pressure codes. The plant itself has set up standardization rules and all equipment conforms to these. Fan noise levels have had to be below the values prescribed by corresponding urban (Technische AnweisungenLuft) codes.

6.10.9 Concluding Remarks

A comparison has been made between wet and dry cooling costs for two units with identical thermodynamics operating in this plant. The results of this comparison have been published (Reference 18).

6.11 DRY COOLING EQUIPMENT AT THE ERDÖL CHEMIE PLANT, DORMAGEN, GERMANY

Date of Visit: October 5, 1975

Participants in the Discussion:

Dipl.-Ing. Krupp, Power Plant Manager

Dipl.-Ing. Heger, Deputy Manager

Simhan-BF

6.11.1 General Remarks

The petrochemical plant Erdöl Chemie is jointly owned by British Petrol and Bayer and is sited at Dormagen, a small town on the western bank of the Rhine about 20 km north of Cologne. The plant delivers basic organic material of petrochemical origin to Bayer as primaries for their own production, and has much the same plant structure as that of Port Jerôme. Boilers with a total steam capacity of about 550 t/h were erected in several phases. The steam produced fulfills the two functions of process steam and power generation. The plant power output capacity is 120 MWe.

Steam conditions at the outlet of the different boiler units differ from each other. After producing electrical energy in back pressure turbines, the steam is fed into the process steam grid at pressure levels of 900, 450, 240 and 90 psia. The dry cooling equipment under discussion handles the exhaust steam of a condensing turbine with 10.3-MWe capacity operating with inlet steam from the 90-psia steam line. This turbine with the corresponding dry cooling equipment went into operation in 1964. In spite of the rather low vacuum (design 1.8 psia, summer maximum 5.25 psia) fuel prices allowed economic utilization of this turbine for electric power production until 1973. Since then, however, increasing oil prices and increasing process steam demands have permitted turbine operation only in winter on days when the demand for process steam is reduced.

The reason for adopting dry cooling was the exhaustion of available fresh water resources, which are utilized mainly for process cooling water, and the high cost of an evaporative system to provide cooling in the power generation sector.

Table 6.11-1 gives the details of the dry cooling equipment.

TABLE 6.11-1. Erdöl Chemie Plant Dry Cooling Equipment Details

Year of commission:	1964
Type of dry cooling equipment:	GEA direct condensing with forced draft
Material:	galvanized elliptic steel tube with steel fins
Tube arrangement:	2 parallel deltas in the form of an isosceles triangle with 70° base angle
Tube length:	7 m
Tube layers:	5 staggered
Design ambient air temperature:	60°F
Number of modules:	24/delta
Number of parallel flow modules:	16/delta
Number of Dephlagmator modules:	8/delta
Design heat rejection capacity:	147×10^6 Btu/h/delta
Design steam conditions:	1.8 psia, 136°F, 8 percent moisture
Steam mass flow:	75 t/h
Number of fans:	3/delta
Fan diameter:	5 m
Fan speed:	167 rpm
Fan power:	6 x 60 kW
Air flow regulation:	two-speed fan with pole variation
Louvers:	no
Wind shields:	no

The deltas are mounted on a steel structure on the roof of the machine house (Figure 6.11-1) with the axis of the deltas running in a north-south direction. Prevailing winds are generally from the northwest. The clearance between the fan blade plane and the roof of the machine house averaged about 8 m, allowing for a slanting roof.

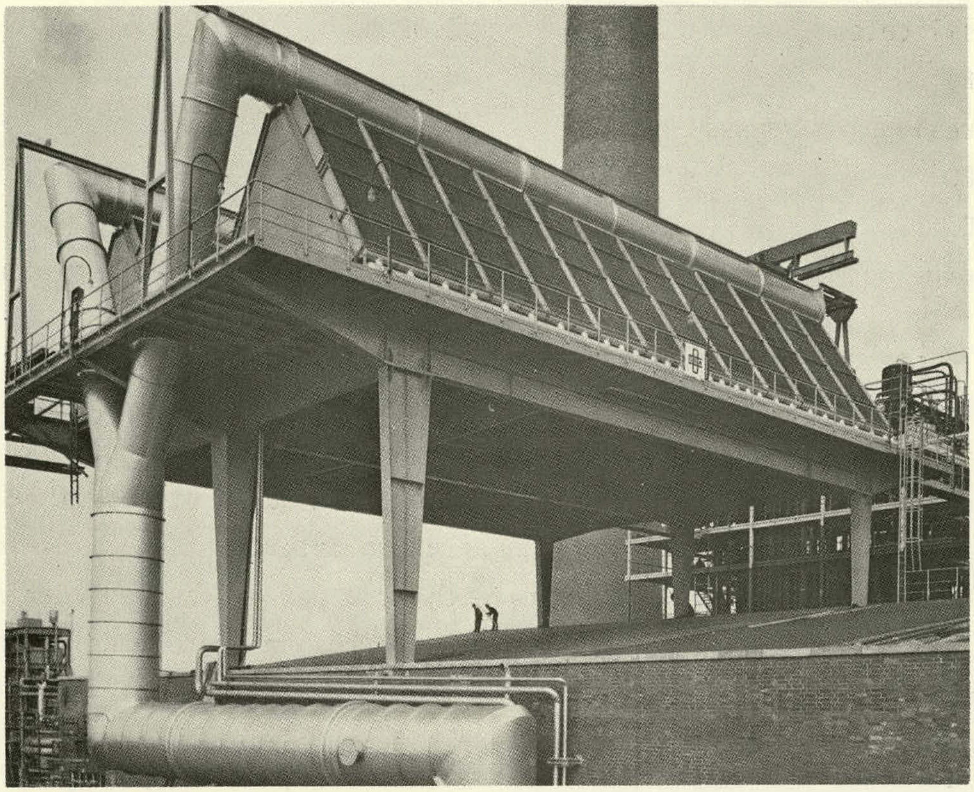


FIGURE 6.11-1. Dry Cooling Equipment at the Erdöl Chemie Petrochemical Plant

6.11.2 Water Quality and Internal Corrosion

Regular inspection of the tubing after every 8000 hours operation has not shown signs of internal corrosion, although the water analyses revealed increasing Fe^{+++} content. In any case, vigilance in this respect has been continuous. During the first inspection, a deposit on the inside of the cooling tubes was recorded. Subsequent investigations have shown that an equilibrium deposit thickness has been achieved. As a precaution, the dry cooling equipment is always held under vacuum whenever it is out of service. Details of a typical condensate analysis are:

pH	9.4 - 9.8
Conductivity	8 μmho/cm
NH_4^+	1.5 - 1.8 mg/ℓ
hydrazine	0.8 - 1 mg/ℓ

silicates	0.02 mg/ℓ
Fe^{+++}	0.01 - 0.02 mg/ℓ
residual hardness	negligible
CO_2	negligible
O_2	0.02 mg/ℓ
organic matter	0.6 - 2 mg/ℓ permanganate equivalent

6.11.3 Air-Side Corrosion and Fouling

The environment at Dormagen has all the characteristics found at a petrochemical plant including high SO_2, dust and organic material concentrations. It was mentioned that a number of modules still within the 6-month guarantee period had shown an undue deterioration of air-side surface quality. These modules then received a new galvanized coating. Since then, the surface quality has undergone corrosion corresponding to the environmental conditions. Plant management feels that the rate of deterioation is acceptable and in no way alarming.

Air-side fouling is a problem of considerable importance, especially because of the comparatively large number of staggered tube layers. Cleaning of the air surfaces is done at least twice a year. Moving galleries have been erected on the deltas for this purpose. Each cleaning campaign involves 36 man-days. Using raw water, 90-psia jets are directed against the modules from the inside as well as from the outside. Repeated jet action is necessary to get rid of the oil film which acts as a bonding agent for the dust. The oil originates from the fan lubrication system. A solution to the problem of reducing the oil carryover has not yet been found.

6.11.4 Seasonal Influence on Operation

Because of the open air construction and the strong radiation of the roof, the dry cooling equipment is difficult to operate in summer. The vacuum decreases rapidly. Internal controls, including throttling of the steam flow to the equipment, assure that the vacuum decrease does not exceed 5.25 psia. Rainy weather markedly improves operation vacuum with gains up to 5 percent having been recorded. Recirculation effects, which probably exist, have not been investigated.

6.11.5 Freezing Experience

The first three years of winter operation were accompanied by freezing incidents. The experience gathered has been systematized and is part of the material discussed in the training of new personnel. Since then freezing incidents have ceased.

Dry cooling equipment is taken off line when the ambient air temperature drops below 20°F. In the range between 20°F and 32°F, careful strategies have been developed to assure freeze-free operation. The fans are turned down and switched on and off according to a fixed rhythm to ensure a uniform temperature over all the modules. Temperatures from six thermocouples on a critical condenser module of both deltas displayed on the control panel facilitate operation during freezing conditions.

6.11.6 Repair and Maintenance

The plant at Dormagen has had more than its share of unexpected repair problems connected mostly with the fans and gear boxes. During the first 3 years, two of the six gear boxes had to be replaced, apparently because of faulty gearing. The gear wheels were evidently subjected to vibration originating from the fan and transmitted through the shafts. For the same reason, gear box bearings frequently failed. Better vibration insulation of the fan assembly has reduced these problems. Dormagen was also the only plant which reported several fan blade failures. The cause for these failures could be the relatively large fan diameter coupled with the vibration experience during the initial stages of plant operation.

Although Dormagen was the only plant with exact figures for repair and maintenance costs for the power installation as the whole, an accounting of the costs specific to the dry cooling equipment is not carried out. The annual budget for repair and maintenance of the whole plant, excluding major overhaul, personnel and other costs, amounts to DM 714,000.-. About 10 percent of this figure should cover the maintenance and repair of the dry cooling equipment. A preventive maintenance philosophy is practiced. Routine maintenance consists of regular weekly inspection of the gear boxes, bearings and fan blades. Twice a year, the gear box lubricating oil is renewed. Shift attendants inspect the dry cooling equipment every 2 hours.

6.11.7 Environmental Standards

Urban regulations require a determination of noise level in the environment throughout the plant site and the contribution of individual noise sources to this overall level. The dry cooling equipment fans are the second loudest contributor to the general noise level. The loudest contributor, however, had such a significant influence on the noise level that noise-reducing measures on this piece of equipment alone sufficed to meet general noise regulations.

6.11.8 Concluding Remarks

The availability of the plant at Dormagen is 99.5 percent. The dry cooling equipment does not reduce this availability in any way. The dry cooling equipment investment totalled DM 1.2×10^6 in 1964 and the 10.3-MWe condensing turbine and generator cost DM 1.44×10^6.

6.12 DRY COOLING EQUIPMENT AT THE WOOD PRODUCT WORKS, WIRUS-WERKE, GÜTERSLOH, GERMANY

Date of Visit: October 9, 1975

Participants in the Discussion:

Ing. Hoppe, Power Plant Manager

Simhan-BF

6.12.1 General Remarks

Probably the oldest existing in Europe, this dry cooling condenser was first commissioned in 1937. It served in a coal mine as part of the equipment of a small power plant and must have been under continuous operation until the end of World War II in Europe. While the history of the equipment during 1945-1948 is uncertain, it is believed that it was not operating. Early in 1949, the present owners bought this equipment from the coal mine and attached it to a condensing turbine with multiple bleeds, which had been acquired from a different source. Since then, the equipment has been under constant use. Thus, the dry cooling equipment now being described has probably the most colorful and quaint history of any covered in this report.

The works at Gütersloh require a relatively large fraction of their steam capacity for processing. A natural circulation boiler, which burns the wood residue originating from the production process (90 percent of the fuel requirement), produces 32 t/h of steam at 870 psia and 960°F superheat. This steam drives a back pressure turbine, which generates 1410 kWe, thereafter exhausting steam at a pressure of 275 psia and a temperature of 760°F. About 10 t/h of the exhaust steam at this pressure level is used as process steam. The rest drives a multiple-bleed condensing turbine generating another power increment of 1.2 MWe. The bleeds at these three different pressure levels also serve process purposes, consuming about 17 t/h of steam. The exhaust steam (maximum of 5 t/h) of the turbine is then condensed in the dry cooling equipment. The power produced satisfies almost 50 percent of plant needs.

The works are situated in an industrial area of Gütersloh which has become the center of the town after post-war expansion. The works consume about 150 t/day of water for open cycle processes. This water is extracted entirely from ground water sources. The dry cooling equipment acquired at nominal cost allowed a smaller-sized water treatment unit, with corresponding savings, than would have been required for an evaporative system.

Details of the dry cooling equipment are summarized in Table 6.12-1.

TABLE 6.12-1. Gütersloh Wood Product Works Dry Cooling Equipment Details

Year of commission:	1937 (recommissioned 1949)
Type of cooling equipment:	Happel System (forerunner of GEA) direct condensing unit with forced draft
Material:	Happel System galvanized elliptical steel tube and steel fins
Tube length:	3.06 m
Tube arrangement:	45° delta erected on steel structure
Tube layers:	2 staggered
Number of modules:	8
Number of condenser modules:	8
Maximum heat rejection capacity:	11.2×10^6 Btu/h
Maximum steam mass flow:	5 t/h
Minimum vacuum:	85 percent (2.2 psia)
Number of fans:	2 (belt driven)
Fan diameter:	3.5 m
Fan speed:	142 rpm (only one speed)
Fan power:	2 x 22 kW
Louvers:	yes, hand operated but now dismantled
Wind shields:	no

6.12.2 Water Quality and Internal Corrosion

The relatively high outlet steam temperatures in the boiler required installation of an extensive water treatment plant including anion exchanger, cation exchanger, degassing equipment and an active charcoal filter. Feed water quality is high as shown by the following typical analysis:

pH	11
p-alkalinity	105 mg/ℓ as $CaCO_3$
m-alkalinity	110 mg/ℓ as $CaCO_3$
phosphates	2-3 mg/ℓ
residual hardness	negligible
Cl^-	10 mg/ℓ
silicates	0.1 mg/ℓ
Fe^{+++}	0.01 mg/ℓ
O_2	negligible

Internal corrosion or fouling has not been observed.

6.12.3 Air-Side Corrosion and Fouling

Personal inspection revealed the quality of the galvanization on the air-side surfaces to be amazingly satisfactory despite the age of the equipment. However, patches of rust are evident especially on those spots where the cooling fins were mistreated through carelessness. The plant manager reported that a corrosion equilibrium has been reached and no problems with regard to air-side corrosion exist.

Air-side fouling consists mainly of sawdust. Once a week, compressed air (60 psia) is used to clean the surfaces, requiring four man-hours.

6.12.4 Freezing Experience

Since 1949, only two freezing incidents have been reported. The cooling tubes especially prone to freezing were those situated between the hinges of the louvers, which, when open, usually stood in a vertical plane perpendicular to the delta sides. The louvers have since been dismantled. During extreme freezing weather, wooden boards are clamped tightly to the delta surfaces. The shift attendant adopts a suitable procedure manually and maintains surveillance of cooling tube temperatures. The dry cooling equipment has never been out of service.

6.12.5 Recirculation, Wind, and Seasonal Effects

Recirculation has been observed although not investigated quantitatively. Indeed, recirculation is welcomed during winter. The cooling equipment is completely surrounded by taller structures. Hence, wind effects are particularly negligible.

The difference in obtainable vacuum between summer and winter operation is about 10 percent (winter 95 percent, summer 85 percent). As soon as the vacuum climbs over 95 percent, the entry valve to the turbine jams shut.

6.12.6 Maintenance and Repair

The power plant undergoes a general inspection once a year. The inspection coincides with the annual 3-week summer vacation. Approximately two man-days are devoted to the dry cooling equipment. Weekly routine cleaning and checks require about one man-day of labor.

6.12.7 Concluding Remarks

The power plant at Gütersloh and especially the dry cooling equipment is reminiscent of an old-time steam locomotive and the slightly eccentric driver who tends it with silent passion. Additional information regarding the Gütersloh facility may be found in Reference 19.

6.13 DRY COOLING EQUIPMENT IN THE SHELL REFINERY, GODORT, GERMANY

Date of Visit: October 10, 1975

Participants in the Discussion:

Dipl.-Ing. Kühne

Simhan-BF

6.13.1 General Remarks

A refinery, originally situated in Hamburg, was originally chosen for two reasons. First, it was believed that the operating experience of a refining plant with dry cooling equipment would be of general interest. Second, the process gas and water coolers rated high on the merit index. Shell requested that the visit be shifted to Godort, where dry cooling equipment of almost the same specifications existed.

6.13.2 Process Gas Condenser

This cooler handles a condensing mixture of hydrocarbons at a pressure of 420 psia and a temperature of 500°F. The heat rejection capacity is 80×10^6 Btu/h and the mass flow through the cooler is 180 t/h. At an ambient air temperature of 105°F, the incoming single-phase gas leaves the cooler as a two-phase homogenous mixture containing 117 t/h uncondensibles and 63 t/h liquid, which is then piped to a separation column. Characteristic of such coolers, the modules with once-through inlet and outlet headers are mounted horizontally on elevated concrete beds with one fan per module. Any desired heat rejection capacity can be provided with the corresponding number of module/fan elements assembled together. Generally the modules are built with steel tubes and cold worked aluminum fins. Nowadays, galvanized steel finned tubes are becoming popular in Europe.

Maintenance centers upon the removal of air-side fouling deposits with water jets. This work is generally subcontracted at a cost of about DM 6.40/m^2 face area.

6.13.3 Concluding Remarks

From the standpoint of experience documentation, this was the most disappointing visit of the European trip because of the paucity of data made available.

6.14 DRY COOLING EQUIPMENT AT THE CENTRAL LIGNITE POWER PLANT, PIETRAFITTA NEAR PERUGIA, ITALY

Date of Visit: October 13, 1975

Participants in the Discussion:

Ing. L. Parodi, Power Plant Manager

Simhan-BF

6.14.1 General Remarks

About 20 km SE of Perugia, a middle-sized town in the uplands of central Italy, medium-sized lignite deposits have been exploited in open mines. The low-grade fuel with a relatively large sand content is fired directly in two independent forced circulation Benson boiler units. Each boiler delivers 118 t/h of steam at 2220 psia and 985°F to two 36-MWe turbines. Exhaust steam from each turbine is condensed in separate, but similar, dry cooling units.

The Pietrafitta power plant is built in the immediate vicinity of Tavernelle near Perugia, and is located on a high plateau with no sources of running water. Artesian wells with an hourly capacity of 120 m^3 are the sole water resources. After chemical treatment this water is used to provide makeup water to the boilers and to supplement water lost in a small auxiliary cooling tower. The cost of treated water is 300 lira/m^3.

The Pietrafitta plant began operation in 1958 at a cost of 12 x 10^9 lira. No exact figures for the cost of the dry cooling equipment were available.

The lignite reserves at Pietrafitta are sufficient to run the power plant for another 12 years. Some minor expansion of the plant output-capacity is planned. This would, however, be based on lignite-fired gas turbines because of the scarcity of water at Pietrafitta. The dry cooling systems have realized all performance expectations and plant management is of the opinion that dry cooling equipment would be satisfactory in power plants with an order of magnitude larger capacity. Table 6.14-1 gives the main details of the dry cooling equipment, together with pertinent thermodynamic data of the power plant.

TABLE 6.14-1. Pietrafitta Power Plant Dry Cooling Equipment and Thermodynamic Data

Power plant design:	2 completely independent boiler-turbine-dry cooling equipment units
Each unit consists of the following components:	
Boiler:	Benson forced convection boiler
Steam supply:	118 t/h, 2250 psia at 985°F, reheat at 480 psia
Turbine inlet temperature:	975°F
Turbine equipment:	1 back pressure turbine in the 2220 psia-450 psia range
	1 condensing turbine in the 420 psia-0.6 psia range
Turbine output:	36 MWe
Dry cooling equipment:	GEA direct condensing equipment with forced draft
Year of commission:	1958
Material:	galvanized elliptical steel tube with steel fins
Tube length:	5.38 m
Tube arrangement:	8 deltas in the form of an isosceles triangle with base angle 53°
Tube layers:	3 staggered
Number of modules:	20/delta
Number of condenser modules:	20/delta
Maximum heat rejection capacity:	197 x 10^6 Btu/h/unit
Maximum mass flow:	86 t/h
Design exhaust steam conditions:	0.6 psia, 105°F
Number of fans:	2/delta
Fan diameter:	5.4 m
Maximum fan speed:	116 rpm, originally 1 speed, now 3-speed

TABLE 6.14-1. (contd)

Air flow:	210 m^3/s/fan
Fan head:	2 in. WG
Fan power:	50 kW/fan
Air flow regulation:	variable entry cross section to fans, 3-speed fans
Louvers:	no
Wind shields:	yes (5 m high)

Pietrafitta is operated as a base load station. Therefore, very little variation occurs in the power output or heat rejection load on the dry cooling equipment.

6.14.2 Water Quality and Internal Corrosion

An elaborate water treatment unit maintains the feed water quality with the following typical analysis:

pH	9.2
p-alkalinity	100 mg/ℓ as $CaCO_3$
m-alkalinity	100 mg/ℓ as $CaCO_3$
phosphates	1 mg/ℓ
silicates	0.06 mg/ℓ
Fe^{+++}	0.05 mg/ℓ
residual hardness	negligible
conductivity	4 μmho/cm
O_2	0.4 mg/ℓ
hydrazine	0.8 mg/ℓ

Checks for internal corrosion are conducted once every year and some top and bottom headers are opened for inspection. These checks show a very thin uniform Fe_3O_4 deposit with a constant thickness. During each 20,000-hour inspection, the dry cooling equipment is filled with nitrogen and kept under a moderate vacuum. No fouling has been observed.

6.14.3 Air-Side Corrosion and Fouling

No air-side corrosion beyond normal wear has been reported. Air-side fouling is a constant problem and the influence of progressive fouling can be seen as a proportional decrease in vacuum from 96 percent to 86 percent. The deposits are mainly fly ash from the dry ash disposal unit. This fine ash can be removed from the 3-layer surfaces only by an elaborate cleaning process consisting of the following steps:

1. Blowing with pressurized air
2. Washing with untreated water jets
3. Blowing with pressurized air to dry the tubes

Twenty man-days per unit are required for this procedure.

6.14.4 Freezing Experience

In the initial stages of plant life freezing incidents were very common. In the last 5 years, no incidents have been reported. This can be attributed to increased experience of the plant personnel. However, 200 tube failures required attention in the last 17 years of plant operation. In the case of a tube failure in the inner layers, the detection of the failure location and repairs are cumbersome. In such cases, the outer tubes must be cut out, the damaged tube replaced, and the tubes cut from the outer layer welded back into place again. The welds are treated with a zinc paint. Such a repair can easily require two to three man-days of effort. Air flow regulation during freezing is achieved by variation of the cross section of entry to the cooler bays. Throttle plates are moved in and out to regulate this area. In addition, alternating operation of the fans is also practiced. However, experience showed that these measures were not adequate to fight the freezing problem effectively. In 1962 and 1963, all fan drives were equipped with three-pole variation motors with suitable gear boxes which now make three-speed fan operations possible.

6.14.5 Maintenance and Repair

The moving parts of the dry cooling equipment are a continuous maintenance problem. Preventive maintenance with regular checks and periodic renewal of gear box lubrication has been the solution to this problem. Every gear box-fan combination is taken out of service after 20,000 hours of service and replaced by a previously overhauled unit. The cost of a unit replacement is 1.3 x 10^6 lira/fan unit. No major stoppage of the dry cooling equipment has ever occurred and the dry cooling equipment has in no way impaired the 96 percent availability of the power plant as a whole.

6.14.6 Recirculation, Wind and Seasonal Effects

Recirculation effects have not been observed. This is attributed to the relatively high (5 m) wind shields and the 3-m entrance skirts around the fan bays. Wind effects have not been analysed. The difference between summer and winter vacuum is as high as 10 percent (86 percent in summer, 96 percent in winter). Rain improves vacuum by about 2 percent.

6.14.7 Concluding Remarks

This plant is an impressive example of a medium-sized power plant with a direct air-cooled condensing system.

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APPENDIX A

OPERATING EXPERIENCE INTERVIEW WORKSHEETS

WORKSHEET 75QM0/0

APPENDIX

ENGINEERING SUPPORT OF ERDA
DRY COOLING TOWER PROGRAM
OPERATING EXPERIENCE INTERVIEW

1. Plant data: (name) (rated power) (heat rate)

2. Location of plant: (city) (country)

3. Type of cooling tower:

	Draft			Heat Rejection (Mw_t)		Tower Manufacture / Plant / Architect-Constructor	Opera (Y
	Mechanical		Natural	Rated	Maximum		
	Induced	Forced					
Dry, direct cycle							
Dry, indirect cycle							
Dry, augmented cooling							
Other							

(identify independent cooling tower systems)

4. Cooling tower cost: (Construction) (percentage of plant cost)
   (local currency - reference year)

5. Rationale for dry cooling: water availability; environmental impact; experiment; other
   (circle appropriate option, explain in 11 below)

6. Overall experience compared to design expectation: better; consistent; worse
   (circle one)

7. Planned additional dry towers: (rating) (type) (when?)

8. What features would improve future operation at this site?

9. For answer to 8, action required by: plant operator; equipment manufacturer; architect;
   (circle appropriate options)

10. Reports or published data are available describing: whole plant; cooling tower; equipmen
    operational history; other
    (circle appropriate options)

11. General Comments:

(basis for design; design options; cost/benefit considerations; expansion of any of above answers; continue on back of form, if necessary)

ENGINEERING SUPPORT OF ERDA
DRY COOLING TOWER PROGRAM
OPERATING EXPERIENCE INTERVIEW

Category: FAILURE MODES

1. Principal failure mode(s) of cooling tower system which resulted in plant shutdown:

   ____
   (e.g. air leakage, corrosion product transport, etc.)

2. Failure frequency for answers in 1: ____________________

   ____

3. Cooling tower failures which were accommodated without plant shutdown: ________

   ____

4. Repair method/ solution for answers in 3: ____________________

   ____

5. Failure frequency for answers in 3: ____________________

   ____

6. Were above failure modes anticipated in design? (no)__________ (yes)________

7. If YES in 6 give specifics: ____________________

   ____

8. Is failure frequency: accelerating; staying constant; reducing; with time?
   (check appropriately)

9. Average annual cost of failures in excess of routine maintenance costs: ________ ($,

   based on ________ (kWhr/yr) ________ (extra manpower) ________ (other
   (specify kW_e or kW_t)

10. Have failure modes necessitated an increase in routine maintenance? (no) ________

11. Failures of cooling tower system chargeable to other plant systems or subsystems: ________

    ____
    (indicate if one-time or recurring events - expand in 15 below)

12. What action would improve failure experience at this site? ________________

13. For answer 12 action required by: plant operator, equipment manufacturer, architect he
    (circle appropriate options)

14. General comments ________________________________

    ____

ENGINEERING SUPPORT OF ERDA
DRY COOLING TOWER PROGRAM
OPERATING EXPERIENCE INTERVIEW

Category: CORROSION (This can supplement the optional attached DETAILED CORROSION QUESTIONNAIRE

1. Type of local environment: urban; rural; industrial; marine; poluted (specify); other.
2. Has corrosion been a problem? (major event)___ (random event)___ (periodic event)_____.
3. Type of corrosion: (airside)____________ (waterside)____________.
4. Cause of corrosion: (in cooling tower) _____ (in plant)_____ (out of plant)_______.
5. If OUT OF PLANT checked in 4, environmental conditions producing corrosion:__________
   ____.
6. Does corrosion go beyond that anticipated in design: (No)_________ (Yes)__________.
7. If NO in 6, give specifics: ______________________________.
8. If YES in 6, how was problem solved/tolerated? ____________________.
9. Corrosion rate is now: (constant)______ (increasing)______ (diminishing)__________.
10. Corrosion product transport experienced: ______________________.
11. Plant downtime chargeable to corrosion: (in cooling tower)_____ (in plant)________.
12. Has corrosion necessitated an increase in routine maintenance? ____________.
13. Average annual cost of corrosion in excess of routine maintenance costs:__________
    ($/kWhr based on)__________ (kWh/yr)__________ (extra manpower)__________
    (other cost)______________________________.(Specify Kw_e or Kw_t
14. What corrosion prevention techniques are practiced?____________________
    ____.
15. What action would improve corrosion experience at this site?______________.
16. For answer to 15, anticipated improvement: ______________________.
17. Are corrosion samples available for analysis? (No)_____ (Yes)_____ (Attached)______.
18. Water/steam/coolant side quality: (Limits)______________________
    (frequency of analysis)__________(chemical addition/control agents)__________.
19. General comments: ______________________________
    (include corrosion from special/unusual effects e.g. wet/dry/spray)
    ____
    ____.

ENGINEERING SUPPORT OF ERDA
DRY COOLING PROGRAM
OPERATING EXPERIENCE INTERVIEW

Category: FREEZING

1. Freezing frequency (Total experience) ______________ (Periodic)______________________

2. Plant downtime due to freezing (1)______________ (2)______________ (3)______________.
(Specify by occurrence)

3. Reduced power operation due to freezing (1)__________ (2)__________ (3)__________.
(Specify by occurrence)

4. Has freezing coincided with peak demand?(No) _______________ (Yes)___________________.

5. Was freezing anticipated in design? (No) _________________ (Yes)____________________.

6. If YES in 5, give specifics ____

____

____.

7. Is freezing tendency increasing (decreasing) with time?_______________________________

____.

8. Can specific average costs, availability or downtime be charged to freezing?
(No)__________ (Yes)__________ ____.
(Specify)

9. Does freezing cause other experience characteristics considered in this questionnaire? fouling, corrosion, maintenance frequency, failure modes, availability, environmental impact (Circle which apply).

10. Potential for improved operation at this site (Action)_______________________________

(Anticipated result)____

11. General Comments ____

____

WORKSHEET 75QMO/5

ENGINEERING SUPPORT OF ERDA
DRY COOLING PROGRAM
OPERATING EXPERIENCE INTERVIEW

Category: MAINTENANCE FREQUENCY

1. Is planned maintenance only performed during planned downtime (No)_______ (Yes)________.

2. If NO in 1, is planned maintenance performed without plant shutdown (No)_____(Yes)____.

3. Ratio planned maintenance/actual maintenance____.

4. Frequency unplanned maintenance caused plant shutdown_______________________________.

5. Frequency unplanned maintenance was performed without plant shutdown_______________

____.

6. Planned maintenance cost ($/manhours)________________ (manhours/yr)________________.

7. Average cost of unplanned maintenance ($/manhour)____________ (manhours/yr)___________.

8. Can a specific fraction of plant downtime be charged to maintenance requirements of cooling tower alone?____

9. Annual structural replacement fraction associated with routine maintenance__________

____.

10. Extraordinary maintenance occurrences during plant history_________________________

____.

11. Potential for improved operation of this site (Action)______________________________

(Anticipated result)____.

12. General Comments____

____

____.

ENGINEERING SUPPORT OF ERDA
DRY COOLING TOWER PROGRAM
OPERATING EXPERIENCE INTERVIEW

Category: FOULING PROPENSITY (Distinguished from Corrosion)

1. Has fouling been a problem: (Ever) (Never) (Periodic)
2. Type of fouling: (Airside) (Waterside) (Material) (Consistency)
3. Source of fouling: ______
4. Critical dimensions of fouling material: ______
5. Atmospheric conditions producing fouling: ______
6. Other environmental conditions producing fouling: ______
7. Was fouling anticipated in design: (No) (Yes)
8. If YES in 7., give specifics: ______
9. Is fouling increasing due to unanticipated conditions: (No) (Yes)
10. If YES in 9., give specifics: ______
11. Loss of cooling tower capability: (Heat Rejection) (Control) (Flow Resistance) (Other
12. Plant downtime chargeable to fouling: ______
13. Maintenance cost for cleanup: ______
14. Average annual cost of maintenance due to fouling: ($/kW-hr) based on (kW-hr/yr) (Specify kW_e or kW_t)
15. Potential for improved operation at this site: (Action) (Expand below in 15) (Result)
16. General Comments: ______

ENGINEERING SUPPORT OF ERDA
DRY COOLING TOWER PROGRAM
OPERATING EXPERIENCE INTERVIEW

Category: ATMOSPHERIC EFFECTS

1. Atmospheric effects experienced at this site are: insignificant; random problem; continuous problem, seasonal problem, wind velocity dependent, other
(Circle appropriate situation)

2. Atmospheric effects at this site change performance of cooling tower: (increase) (decrease

3. If DECREASE indicated in 2, heat rejection capability loss: (Mwt average) (Mwt peak)

4. Do atmospheric effects coincide on average with peak demand: (No) (Yes) (Indeterminate)

5. Were atmospheric effects anticipated in design: (No) (Yes)

6. If YES in 5, give specifics:

7. Are average atmospheric effects changing with time or other environmental conditions?
(No) (Yes)

8. Can specific cost, availability or downtime be charged to atmospheric effects?
(No) (Yes)
(specify)

9. Do atmospheric effects cause or influence other experience characteristics considered in this questionnaire? (fouling) (corrosion) (recirculation) (freezing) (maintenance frequency) (failuremode) (availability) (codes & standards) (environmental impact)
(check which apply)

10. Potential for improved operation at this site: (Action)
(Anticipated result)
(Expand below in 11)

11. General Comments:
(Discuss enhancement of capabilities from rain/fog, etc.)

ENGINEERING SUPPORT OF ERDA
DRY COOLING TOWER PROGRAM
OPERATING EXPERIENCE INTERVIEW

Category: RECIRCULATION

1. Is there any observed behavior attributable to recirculation? (No) (Yes) ______

2. Does recirculation decrease (increase) cooling tower performance? ______ (No) (Yes)

______ (Specify alternate)

3. If decrease indicated in 2., capability loss: (Average kW_t) (Peak kW_t)

4. Is recirculation seasonal? ______ (No) (Yes) ______

5. Does recirculation coincide with peak demand? ______ (No) (Yes) ______

6. Was recirculation anticipated in design? ______ (No) (Yes) ______

7. If YES in 6., give specifics: ______

8. Is recirculation experience changing with time? ______ (No) (Yes) ______

9. Can specific costs, availability or downtime be changed to recirculation:

______ (No) (Yes) ______

10. Does recirculation cause other experience characteristics considered in this questionnaire? (fouling) (corrosion) (freezing) (maintenance frequency) (failure modes) (availability) (environmental impact)
(circle those which apply)

11. Potential for improved operation at this site: ______ (action) ______

______ (anticipated result) ______
(expand below in 11)

12. General comments: ______

______

______

ENGINEERING SUPPORT OF ERDA
DRY COOLING PROGRAM
OPERATING EXPERIENCE INTERVIEW

Category: AVAILABILITY

1. Average plant availability ______________________________

2. Does cooling tower system influence plant availability (No)__________ (Yes)__________

3. Specify if YES in 2, greater than, less than, other components ______________

4. Has cooling tower system availability changed with age? (No)__________ (Yes)__________

5. Was a specific reliability designed into cooling tower? (No)__________ (Yes)__________

6. If YES to 5, in which respects? ______________________________
(e.g. environmental, corrosion, fouling, freezing)

7. Has availability been achieved at the expense of a planned or preferred maintenance schedule? (No)__________ (Yes)______________________

8. Potential for improved availability at this site (Action)______________________
(Anticipated result)______________________________

9. General Comments ______________________________

____

____

ENGINEERING SUPPORT OF ERDA
DRY COOLING PROGRAM
OPERATING EXPERIENCE INTERVIEW

Category: CODES AND STANDARDS

1. Did construction of cooling tower system follow established codes and standards? (No) (Yes)
2. Were these codes and standards used to qualify cooling tower? (construction) ______ (operation) ______
3. Principal construction codes/standards (1) ______ (2) ______ (3) ______
4. Principal operating codes/standards (1) ______ (2) ______ (3) ______
5. If NO in 1, has impact been experienced in other characteristics (fouling, freezing, corrosion, wind effects, recirculation, maintenance frequency, failure modes, availability, environmental impact) ______
6. What undesirable experience could have been avoided if codes/standards existed? ______
7. Need for improved codes/standards (Action) ______ (Anticipated result) ______
8. General Comments ______

ENGINEERING SUPPORT OF ERDA
DRY COOLING PROGRAM
OPERATING EXPERIENCE INTERVIEW

Category: ENVIRONMENTAL IMPACT/SITING

1. Number of environmental complaints expressed: ______________________________

____

2. Nature of complaints in 1: ______________________________

3. Disposition of complaints in 1: ______________________________

4. Has there been an environmental monitoring program to quality cooling towers at this site? (No)______________ (Yes)______________

5. Has cooling tower environmental impact changed with age of plant?______________

____

6. Was total environmental impact reviewed at time of construction? (No)_____ (Yes)_______

7. Potential for improved operation at this site: (Action)______________
(anticipated result)______________________________

8. Is adequate climatological information available in convenient statistical summaries to permit planning and design optimization? (No)________ (Yes)______________
(If YES explain in 9 below)

9. General comments ______________________________

____

____

APPENDIX B

PHASE I LITERATURE SURVEY

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