

CASE STUDY NO. 21

**ESTABLISHMENT OF OPTIMUM FEED WATER CLEANING METHOD
FOR KAINAN UNIT NO. 4 THROUGH DESIGN OF EXPERIMENTS**

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1. INTRODUCTION

The Thermal Power Department of the Kansai Electric Power Co. is committed to maintaining and improving thermal efficiency through its TQC activities.

At the Kainan Power Plant, which has the second largest rating of power generation (2,100,000 kW) among our thermal power plants, a variety of measures aimed at maintaining and even enhancing equipment performance has been put into action to prevent performance deterioration which effects thermal efficiency.

This paper presents a brief description of the measures successfully practiced, by design of experiments and other techniques, to prevent deterioration in the performance of condensers, which is so important for the thermal efficiency.

2. CONDENSER SUMMARY

In the thermal power plant, fuel is first combusted in the boiler to generate steam, as shown in Figure 1; the steam turns a turbine directly coupled to the generator to generate power.

After the steam has turned the turbine, the condenser cools it with sea water so as to return it to a liquid state. The internal space of the condenser is maintained in a vacuum condition by condensation of the steam.

The vacuum is used as a measure of this condition. As can be seen from the cause and effect diagram in Fig. 1, as the cooling effect is reduced by dirt and other foreign matter (scales) on the internal surfaces (see water side) of the condenser tubes, the vacuum drops, impairing thermal efficiency.

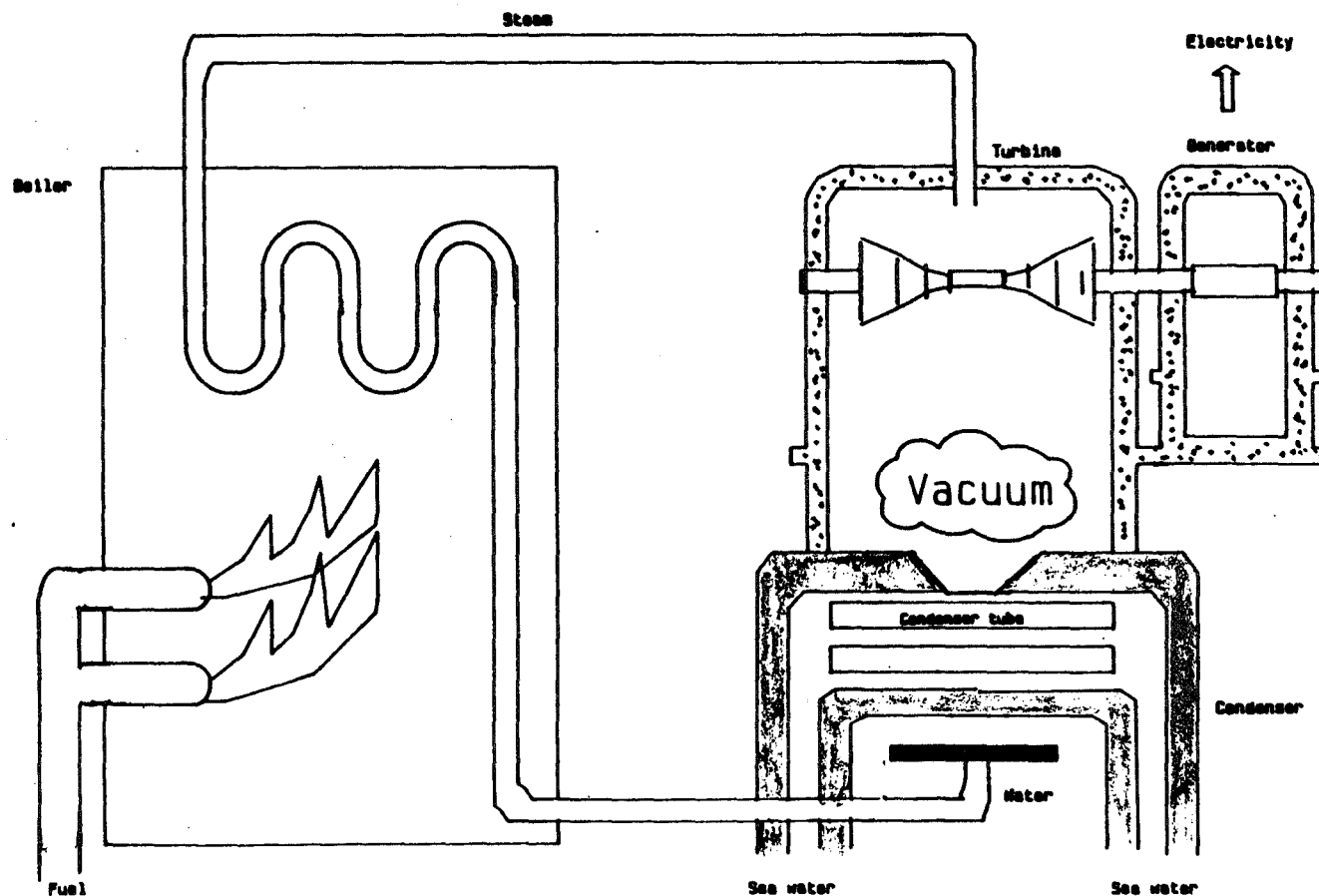
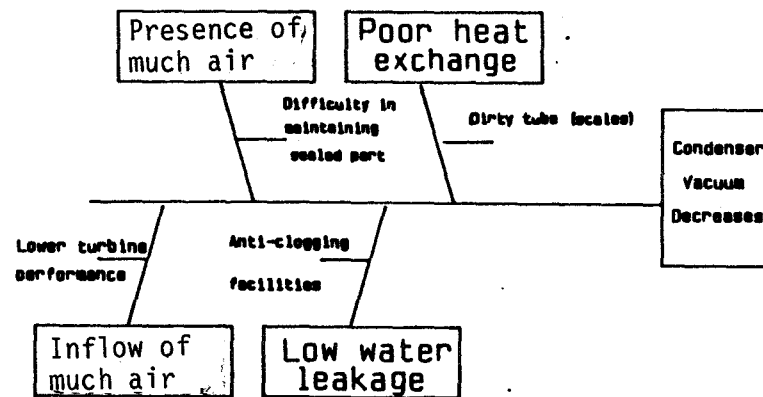


Figure 1 Power plant schematic and cause-and-effect diagram showing decline in the condenser vacuum

3. UNDERSTANDING THE CURRENT SITUATION AND FACTOR ANALYSIS

The condenser vacuum of Kainan Unit No. 4 was lower than at the start of plant commissioning in Fiscal 1973, the primary reason being the increased adhesion of scales to the internal surfaces of the condenser tubes.

4. GOAL SETTING

The goal was to restore the condenser vacuum to its level at the start of plant commissioning (718 mmHg or higher).

5. DISCUSSION OF COUNTERMEASURES

Cleaning the condenser tubes was initially adopted as a means of helping to restore the condenser vacuum. After a comprehensive review of effectiveness, expenditure, and other pertinent factors, cleaning by the use of carborundum balls, which had a proven record of performance in our company, was carried out in September 1984.

This cleaning method, however, was unfit for the geometry of the condenser in Kainan Unit No. 4, and fell short of expectations. After repeated reviews, cleaning by pressurized jet water was chosen (see Figure 2).

But because we had had no prior experience with this cleaning method and the power plant equipment operation procedures and the quality of sea water varied from one plant to another, the suitability of the cleaning conditions observed at other power plants for the Kainan Power Plant was unknown.

Therefore, it was decided to establish the cleaning conditions representing an optimal trade-off between effectiveness and expenditure through design of experiments.

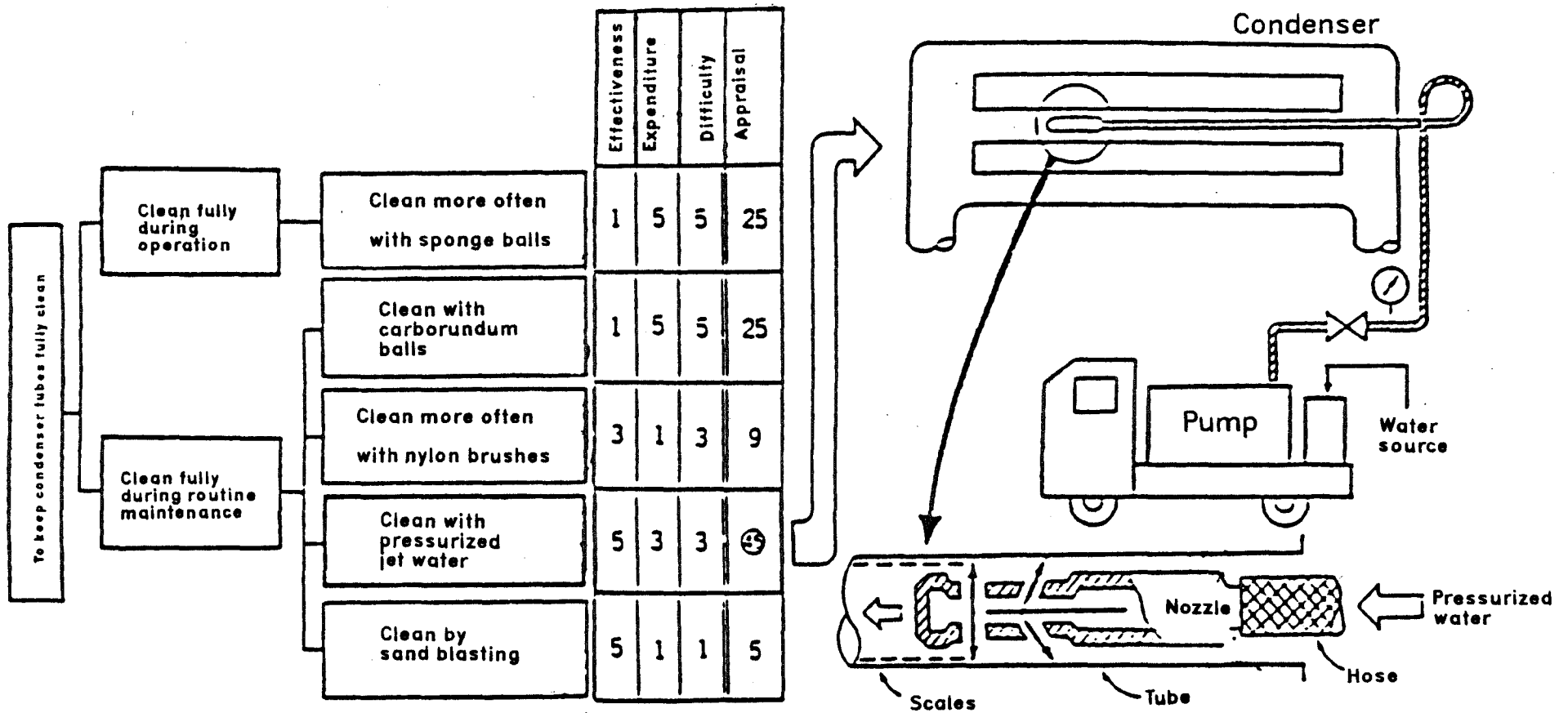


Figure 2 Countermeasure system diagram and pressurized jet cleaning schematic

5.1 POINTS TO CHECK BY EXPERIMENTATION

With tube maintenance taken into consideration, the following two items were selected as points to check experimentally:

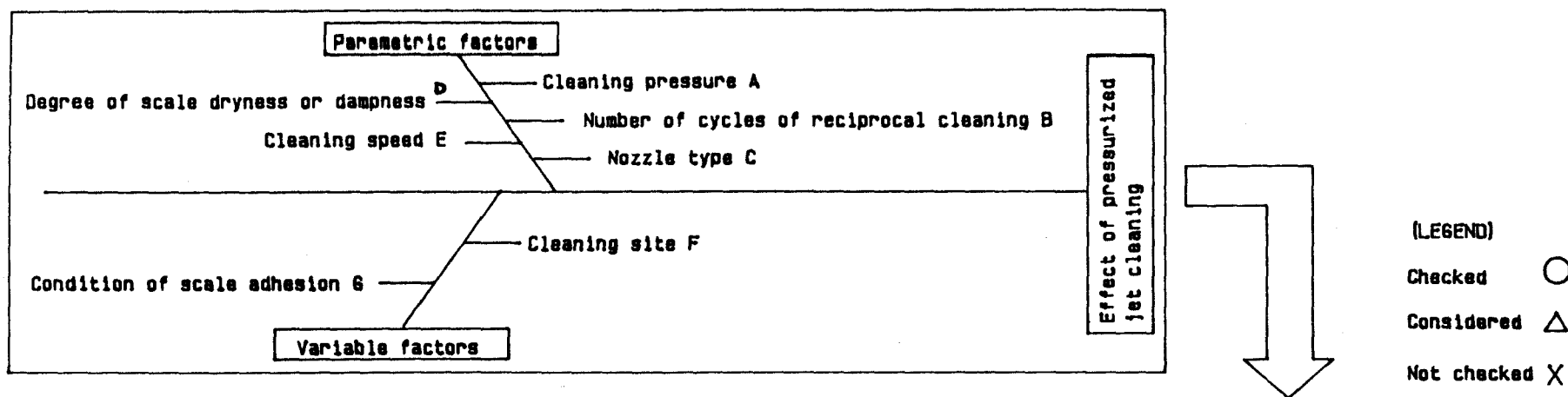
- Cleaning effect
Amount of residual scales (Characteristic value based on design of experiments)
- Effects on the condenser tube
Conditions of damage to the condenser tube (such as erosion and perforation)

The cleaning cost was factored together with these check points for the purpose of developing an actual cleaning plan.

5.2 SELECTION OF EXPERIMENTAL FACTORS

Factors influencing the cleaning effect are shown in the cause-and-effect diagram in Figure 3. These factors were then reviewed from the technical viewpoint to single out the following four factors for experimental purposes:

- A. Pressure of the jet cleaning water
- B. Number of cycles of reciprocal motion of the cleaning nozzle in the condenser tubes
- C. Type of the cleaning nozzle
- D. Degree of scale dryness or dampness



FACTOR			EXPLANATION	Selection
Parametric factors	A	Cleaning pressure	It is necessary to check the cleaning effect associated with increases in the cleaning pressure, and the influence it may have on the condenser tube.	○
	B	Number of cycles of reciprocal cleaning	It is necessary to evaluate the cleaning effect associated with increases in the cleaning frequency, and the expenditure and construction period involved.	○
	C	Nozzle type	It is necessary to check the cleaning effect associated with the number of holes in the nozzle, and the influence it may have on the condenser tube.	○
	D	Degree of scale dryness or dampness	Normally, the scales are damp immediately after the start of routine inspection. It is necessary to check this factor because a better cleaning effect may be obtained with dry scales.	○
	E	Cleaning speed	Generally, a cleaning speed of 1 or 0.5 m/s is practiced, but no noticeable difference has been reported in available literature. For operability's sake 1 m/s is used.	X
Variable factors	F	Cleaning site	Technically, cleaning sites are unlikely to make differences in the cleaning effect. It is not necessary to check this factor, because variations in the amount of scale adhesion are considered to have a greater effect.	X
	G	Condition of scale adhesion	Since the cleaning method cannot be altered according to the condition of scale adhesion, experiment with the condenser tube having the largest amount of scale adhesion.	Δ

Figure 3 Selection of experimental factors

5.3 DISCUSSION OF EXPERIMENT METHODS

It was decided to choose the combination of experiments that would minimize the cost of experimenting while isolating as much as possible the effect of each factor.

As shown in Figure 4, discussions of the possible experiment combinations, beginning with the nozzle type posing the most difficult level change, revealed that partial randomization (three-division method) could be accomplished at the lowest cost. One problem was the ~~existence~~ of some interaction with errors, as can be seen from the structural formula, but the experiment combination was technically assumed to have only a slight influence on the cleaning effect.

confounding

Difficulty of level change			
FACTOR	Number of levels		Diffi- culty
Cleaning pressure A (kg/cm ²)	200	250 300	△
Number of cycles of reciprocal cleaning B (cycles)	1	2	○
Nozzle type C	C ₁	C ₂	×
Scale dryness or dampness D	Dry	Damp	○

○ Easy △ Somewhat difficult × Difficult

Discussion of combinations

Method	Configuration	Cost	Feature
1. Complete randomization (three repetitions)		950,000 (72 times)	- Poor workability and high cost due to need for frequent nozzle changes
2. Complete randomization (two repetitions)		630,000 (48 times)	- Somewhat lower cost due to fewer repetitions required
3. Partial randomization (two-division method)		540,000 (72 times)	- little need for nozzle change - confounding of (CxB) with first-order error
4. Partial randomization (three-division method)		400,000 (72 times)	- low cost - confounding of (CxB) with first and second-order errors

[---] Note: Randomized within dotted lines.

Determination of the experimental method

(FACTOR)	(Experiment structure)
C _i : Nozzle type	C ₁ (C1 nozzle) C ₂ (C2 nozzle)
B _i : Number of cycles of reciprocal cleaning	B ₁ B ₂ B ₁ B ₂ (1 cycle) (2 cycle) (1 cycle) (2 cycle)
A _i : Cleaning pressure (kg/cm ²)	A ₁ A ₂ A ₃ (200) (250) (300)
D _i : Scale dryness or dampness	D ₁ D ₂ (Dry) (Damp)
m : Repetition	

(Structural formula)

$$x_{ijk} = \mu + C_i + B_j +$$

$$(C3)_{ij} + 2(1)_{ij}$$

$$+ A_k + (CA)_{ik} + (BA)_{jk} +$$

$$(C3A)_{ijk} + 2(2)_{ijk}$$

$$+ D_l + (CD)_{il} + (BD)_{jl} + (AD)_{kl}$$

$$+ (C3D)_{ijl} + (CAD)_{ijk} + (BAD)_{jkl}$$

$$+ (C3AD)_{ijkl} + e(3)_{ijklm}$$

5.4 EXPERIMENT

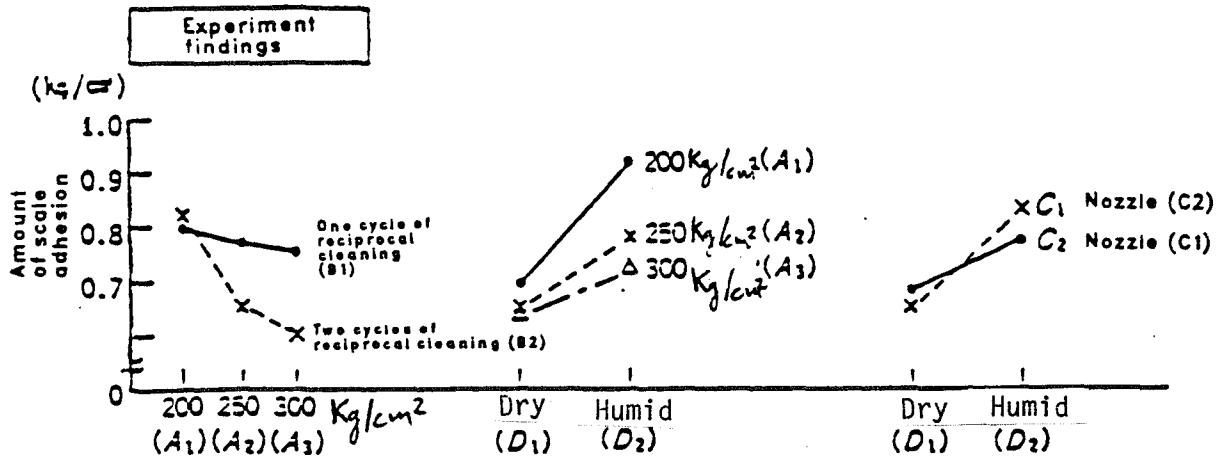
Eight Tubes were removed from the condenser and the amounts of scale adhesion to them were measured (at five points per tube). Then, 72 samples were prepared from around the point found to have the largest amount of scale adhesion and subjected to experiment in July 1985.

5.5 EXPERIMENT FINDINGS AND CLEANING PLAN

The experiment findings are summarized in Fig. 5. Apparently, the degree of scale dryness or dampness and the cleaning pressure were found significant, each with a 1% level of significance, the number of cycles of reciprocal cleaning was significant with a 5% level of significance.

The optimal conditions were then established by factoring cost data of one and two cycles of reciprocal cleaning into these findings. The optimal cleaning conditions thus determined were a cleaning pressure of 300 kg/cm², one cycle of reciprocal cleaning, dry scales, and the C2 nozzle.

No damage at all was observed in all the cases of tube cleaning.



Variance analysis Table (i)

FACTOR	Sum of squares	Degree of freedom	Unbiased variance	Variance ratio
C	0.0052	1	0.0052	4.73
B	0.1097	1	0.1097	99.73
e_1	0.0011	1	0.0011	1 >
A	0.2109	2	0.10545	24.24
$C \times A$	0.0108	2	0.0054	1.24
$B \times A$	0.0824	2	0.0412	9.47
e_2	0.0087	2	0.00435	10.21
D	0.3376	1	0.3376	16.27
$C \times D$	0.0425	1	0.0425	2.95
$B \times D$	0.0016	1	0.0016	1 >
$A \times D$	0.0548	2	0.0274	1.32
$C \times B \times D$	0.0007	1	0.0007	1 >
$C \times A \times D$	0.0235	2	0.0118	1 >
$B \times A \times D$	0.0048	2	0.0024	1 >
$C \times B \times A \times D$	0.0075	2	0.00375	1 >
e_3	0.9959	48	0.02075	—
TOTAL	1.8998	71	—	—

Note: Factors marked with 0 are pooled.
 * 5% level of significance
 ** 1% level of significance

Variance analysis Table (ii)

FACTOR	S	ϕ	V	F	E(V)
B	0.1097	1	0.1097	6.31	$\sigma_e^2 + 35\sigma$
A	0.2109	2	0.10545	6.05	$\sigma_e^2 + 24\sigma$
$B \times A$	0.0824	2	0.0412	2.37	$\sigma_e^2 + 12\sigma$
D	0.3376	1	0.3376	19.40	$\sigma_e^2 + 35\sigma$
$C \times D$	0.0425	1	0.0425	2.44	$\sigma_e^2 + 18\sigma$
e	1.1167	64	0.0174	—	σ_e^2
TOTAL	1.8998	71	—	—	—

Economics study

Optimal cleaning conditions

FACTOR	Cleaning pressure	Scale dryness or dampness	Number of cycles of reciprocal cleaning	Noz typ
level	300 kg/cm^2	Dry	Once	C_2 n

Figure 5 Experiment findings and optimal cleaning conditions

5.6 EXPECTED EFFECTS

The amount of scale adhesion after cleaning under these optimal conditions was predicted to be 09.66 ± 0.08 mg/cm² on the average. When 40 samples were prepared from the eight condenser tubes and subsequently cleaned under the optimal conditions, the amount of scale adhesion was found to average 0.75 mg/cm². The vacuum calculated from this result was 719 mmHg, which was in good agreement with the vacuum goal set earlier.

6. IMPLEMENTATION OF COUNTERMEASURES

In view of the successful performance of condenser tube cleaning in both experiments and production machine tests, cleaning of 46,000 tubes was conducted in January 1986.

7. FUTURE PLANS

Plant operation is scheduled to start after April 1986, after a review of the conditions of damage to all the tubes and anticorrosion action subject to a sampling survey of scale adhesions (components, amounts of adhesion, etc.).

After the start of the plant operation, efforts will be directed at standardizing cleaning procedures by verifying post-operation effects and lessening the amounts of scale adhesion to better sustain the effects achieved.

8. CONCLUSION

In the past, cleaning was thought to be more effective when the scales were damp, but through the present application of design of experiments it was revealed that cleaning was more effective when the scales were rather dry.

The present experiments have allowed us to establish a cleaning method that can provide a quantitative basis. The author is also concerned with the introduction of more statistical techniques in day-to-day job scenes to better expedite workflow.

(May 1986)