# Determination of Optimum Operation Time for Phosphoric Acid Evaporators

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## ABSTRACT

A mathematical model based on the fundamental heat transfer correlations has been derived and fitted by experimental data measured from a full scale phosphoric acid plant in order to calculate the optimum operation time for phosphoric acid evaporators. The mathematical model may be used to determine the optimum operation time for the other industrial applications if it is refitted by the full-scale data of the deterioration of heat transfer coefficient with time.

## 1-INTRODUCTION

The scale formed on the heat transfer surface of evaporators lowers the heat transfer coefficient with time. After a period of time the evaporators has to be shutdown and cleaned. The cleaning time is about 24 hours, during which the evaporators are out of service. Too long operation time without cleaning means that the evaporator will operate for a considerable time at too low heat transfer coefficient, on the other hand too short operation time means that the evaporators will be out of service, for cleaning, more frequently.

The optimum operation time for any evaporators may be predicted using a correlation derived through a mathematical model based on the fundamental heat transfer principles.

The mathematical model has been fitted by experimental data from a full-scale phosphoric acid evaporation plant. The plant is located in Abu-Zaabal, Cairo. Egypt concentrating phosphoric acid from 28% $P_2O_5$ up to 52%$P_2O_5$. The deterioration of heat transfer coefficient of the evaporators has been measured during the period between two washing cycles.

## 2-Experimental Measurements

The deterioration of the overall heat transfer coefficient in the period between two washing cycles for the full scale forced circulation evaporators used for concentration of phosphoric acid from about 28% $P_2O_5$ up to 52%$P_2O_5$ Abu-Zaabal, Cairo. Egypt has been measured and calculated.

The measured values of the overall heat transfer coefficient are shown in table (1)

**Table (1) measured Values of overall heat transfer coefficients**

| Time, hours | U, Btu/hr $ft^2$ °f |
|---|---|
| 0 | 180 |
| 12 | 176 |
| 36 | 167 |
| 60 | 158 |
| 84 | 149 |
| 104 | 144 |

By plotting the rate of deterioration of heat transfer coefficient with time, a strait line is obtained as shown in figure (1).

The straight line equation may be written as follow:

$$U = U_c - K\theta \quad (1)$$

Where:

U: heat transfer coefficient at time $\theta$

$U_c$: clean heat transfer coefficient

K: heat transfer deterioration constant

$\theta$: operation time

The correlation that best fits figure (1) may be written as follows:

$$U = 180 - 0.35\theta \quad (2)$$

Where:

U in Btu/hr $ft^2$ °f

$\theta$ in hours

## 3-MODEL DEVELOPMENT

The Optimization Concept based on maximizing the total heat transferred through the evaporators heating surface "$Q_T$" during the lifetime of the evaporator "L"

From the fundamental heat transfer principles

$$\frac{dQ}{d\theta} = UA\Delta t \quad (3)$$

Where

Q: heat transferred during one operation cycle time □

A: heat transfer area

Δt: temperature difference

By substituting U from equation (1)

$$\frac{dQ}{d\theta} = (U_c - K\theta A\Delta t)$$

By integration:

$$Q = A\Delta t \int_0^{\theta} (U_c - K\theta) d\theta$$

$$Q = A\Delta t \Big|_0^{\theta} U_c\theta - \frac{K}{2}\theta^2$$

$$Q = A\Delta t\left(U_c\theta - \frac{K}{2}\theta^2\right) \qquad (4)$$

The total number of operation cycles "N" during the lifetime of the evaporator "L" may be expressed as

$$N = \frac{L}{(\theta + C)} \qquad (5)$$

Where

C: time required for cleaning the heating surface

The total heat transfer through the evaporator heating surface "$Q_T$" may be expressed as

$$Q_T = Q * N \qquad (6)$$

$$Q_T = A\Delta t\left(U_c\theta - \frac{K}{2}\theta^2\right)\frac{L}{(\theta + C)}$$

$$Q_T = \frac{AL\Delta t}{2}\left(\frac{2U_c\theta - K\theta^2}{(\theta + C)}\right) \qquad (7)$$

By differentiang equation (7) to maximize" $Q_T$"

$$\frac{dQ_T}{d\theta} = \frac{AL\Delta t}{2}\left(\frac{(\theta + C)(2U_c - 2K\theta) - (2U_c\theta - K\theta^2)}{(\theta + C)^2}\right)$$

$$\frac{dQ_T}{d\theta} = \frac{AL\Delta t}{2}\left(\frac{2CU_c - 2CK\theta - K\theta^2}{(\theta + C)^2}\right) \qquad (8)$$

At $Q_T$ maximum $\frac{dQ}{d\theta}=0$

Hence:

$$\theta^2+2C\theta-\frac{2CU_c}{K}=0$$

$$\theta=\frac{-2C\pm\sqrt{4C^2+8CU_c/K}}{2} \qquad (9)$$

By redifferentiating equation (8):

$$\frac{d_2Q_T}{d\theta^2}=AL\Delta t\frac{d}{d\theta}\left(\frac{CU_c-CK\theta-\frac{K}{2}\theta^2}{(\theta+C)}\right)$$

$$\frac{d_2Q_T}{d\theta^2}=-Al\Delta t\left(\frac{C^2K+2CU_c}{(\theta+C)^3}\right) \qquad (10)$$

In any evaporator; A, L, Δt, C, K and $U_c$ are positive values

Therefore:

$$\frac{d_2Q_T}{d\theta^2}=-ve$$

Hence the first derivative is a maximum

## 4-Application to Phosphoric Acid Evaporators

For phosphoric acid evaporators using the measurements obtained from Abu-Zaabal plant, Cairo-Egypt:

$U_c$=180 Btu/hr $ft^{2\circ}$ f

K=0.35 Btu/hr $ft^{2\circ}$ f

C=24 hours

By substitution in equation (9) we obtain that:

$\theta$ =135 hours

### 4.1-Effect of cleaning time

The cleaning time "C" has significant effect on the optimum operation time "$\theta$". The shorter the cleaning time the shorter the optimum operation time and the higher the operation heat transfer coefficient.

Table (2) shows the effect of cleaning time "C" on operation time" $\theta$ " and the minimum heat transfer coefficient at the end of the operation.

**Table (2) effect of cleaning time optimum operation time and heat transfer coefficient**

| Cleaning time C, hr | Operation time $\theta$, hr | Minimum heat transfer coefficient Btu/hr $ft^{2\circ}$ f |
|---|---|---|
| 8 | 83 | 151 |
| 12 | 96 | 146 |
| 16 | 113 | 140 |
| 24 | 135 | 133 |
| 36 | 160 | 125 |

Schematic presentations of table (2) are shown in figure (2) and figure (3) :

### 4.2-Practical Considerations

In order to shutdown an evaporation plant for cleaning or for regular maintenance, usually it is done at the end of a shift and the start of a new one.

Usually the plant shift is either 8 or 12 hours. According to the above criterion the relation between the optimum operation time $\theta$ and cleaning time C may be shown in table (3).

**Table (3) practical operation time and corresponding minimum heat transfer coefficient**

| Cleaning time ,C,hr | 8 hours shift plant | | 12 hours shift plant | |
|---|---|---|---|---|
| | $\theta$,hr | U, Btu/hr ft$^{2\circ}$ f | □,hr | U, Btu/hr ft$^{2\circ}$ f |
| 8 | 80 | 152 | - | - |
| 12 | - | - | 96 | 146 |
| 16 | 112 | 141 | - | - |
| 24 | 136 | 132 | 132 | 134 |
| 36 | - | - | 156 | 125 |

Schematic presentations of table (3) are shown in figures (4), (5), (6) and figure (7) as follows:

## *5. References*

1- Abu-El Azm R.A.M. "optimum Process Design for phosphoric Acid Concentration scheme", ph. Thsis.1998

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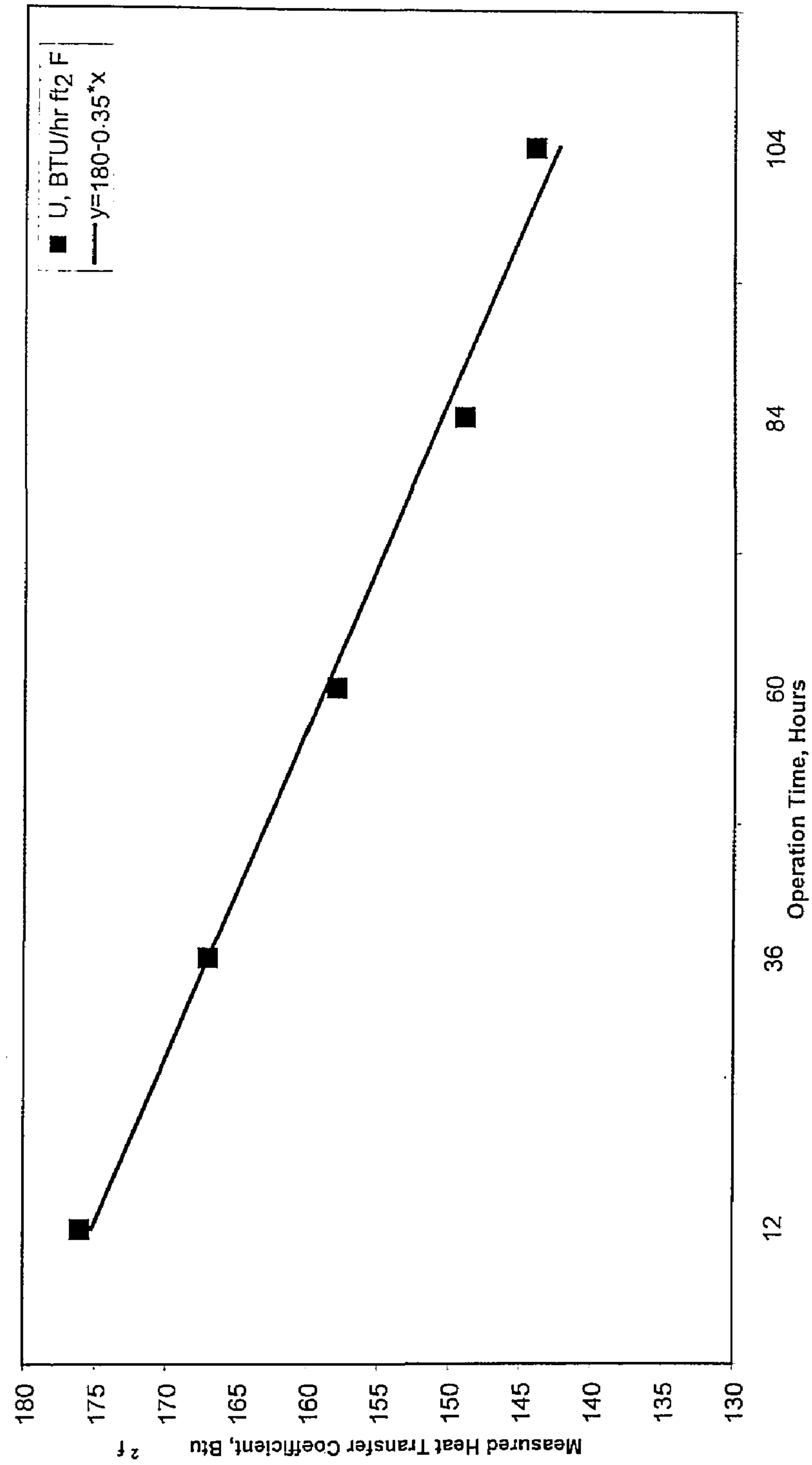


Fig. (1):Measured Values of Overall Heat Transfer Coefficients

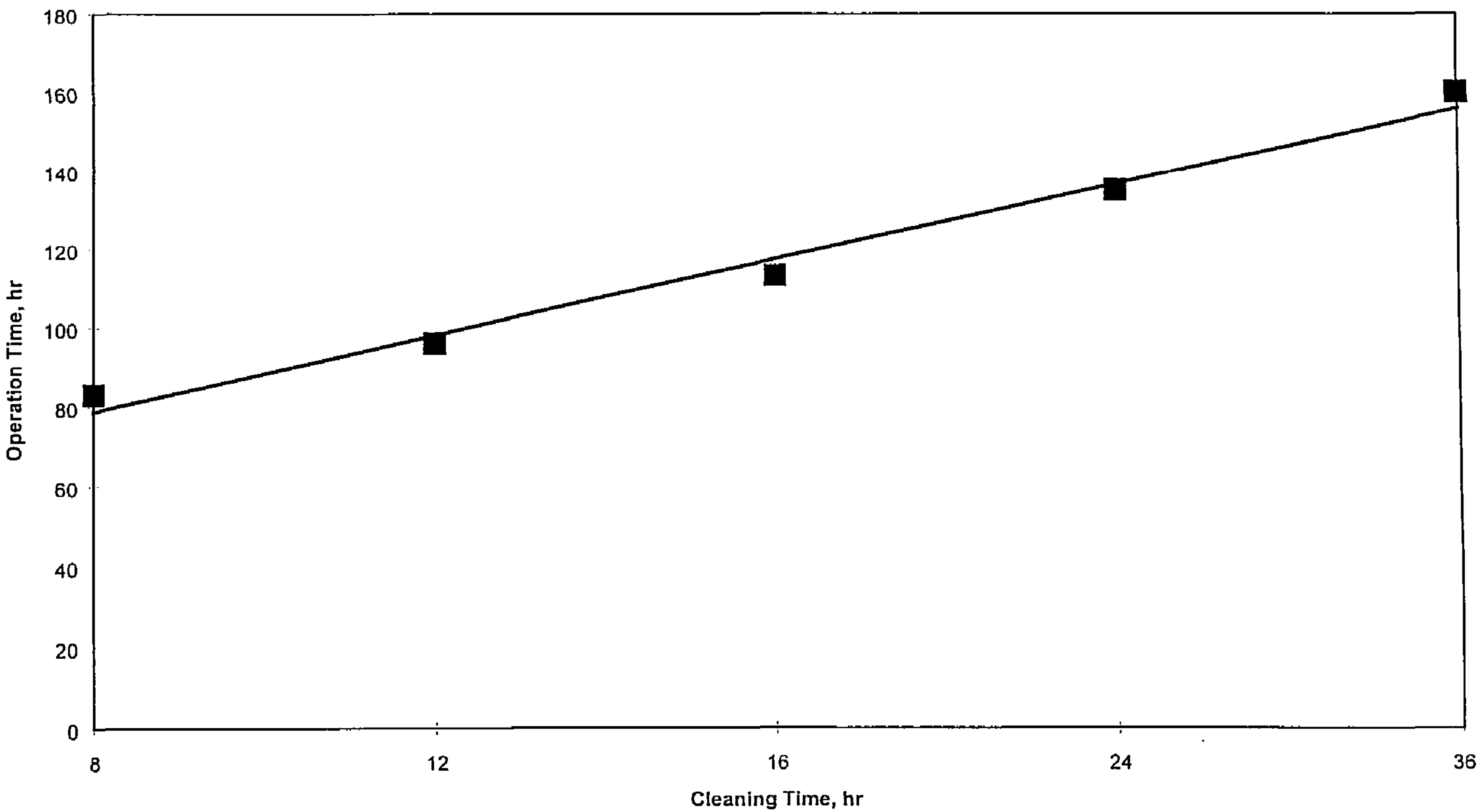


Fig. (2) Effect of cleaning time on operation time

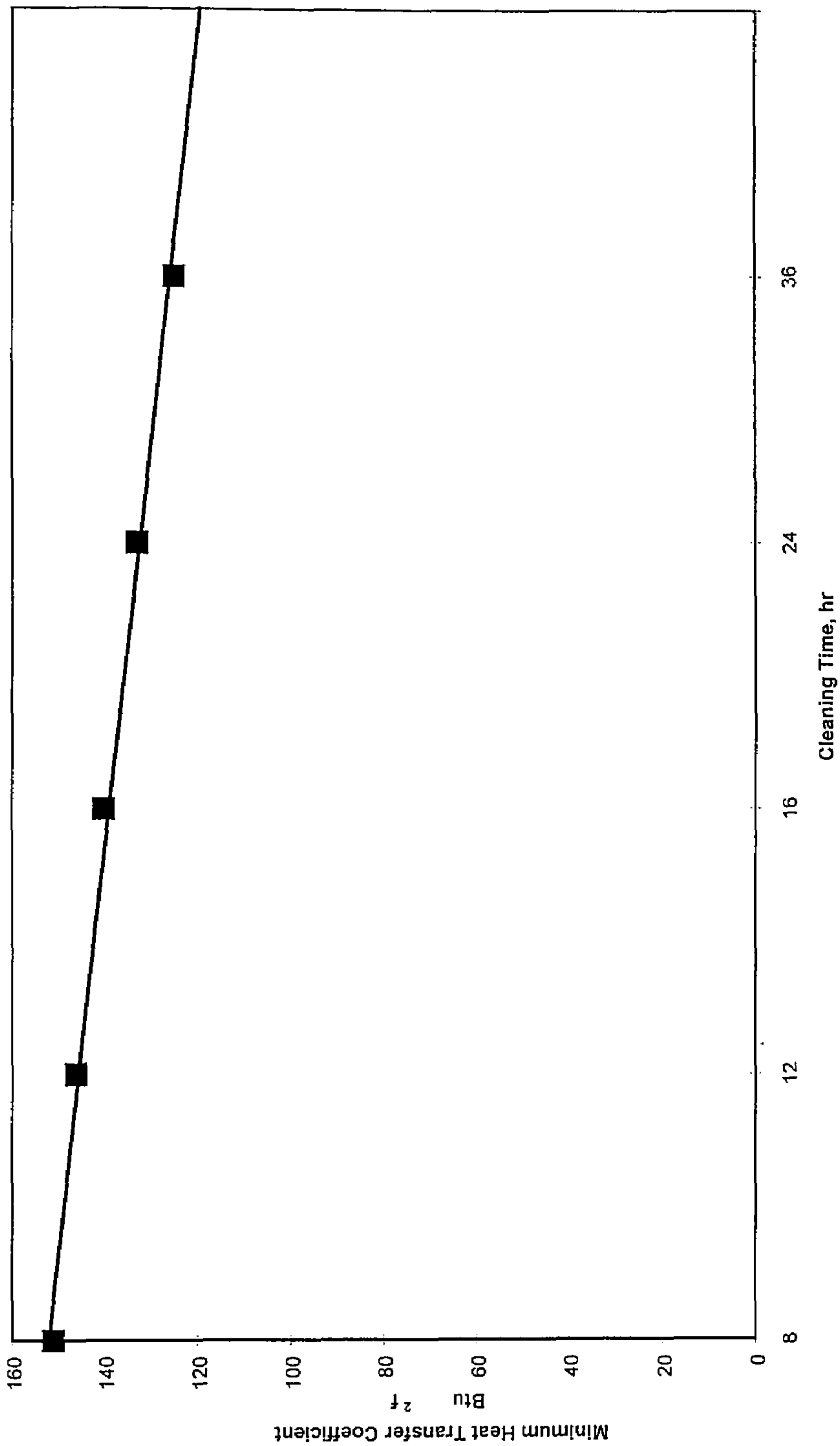


Fig. (3) Effect of cleaning time on minimum heat transfer coefficient

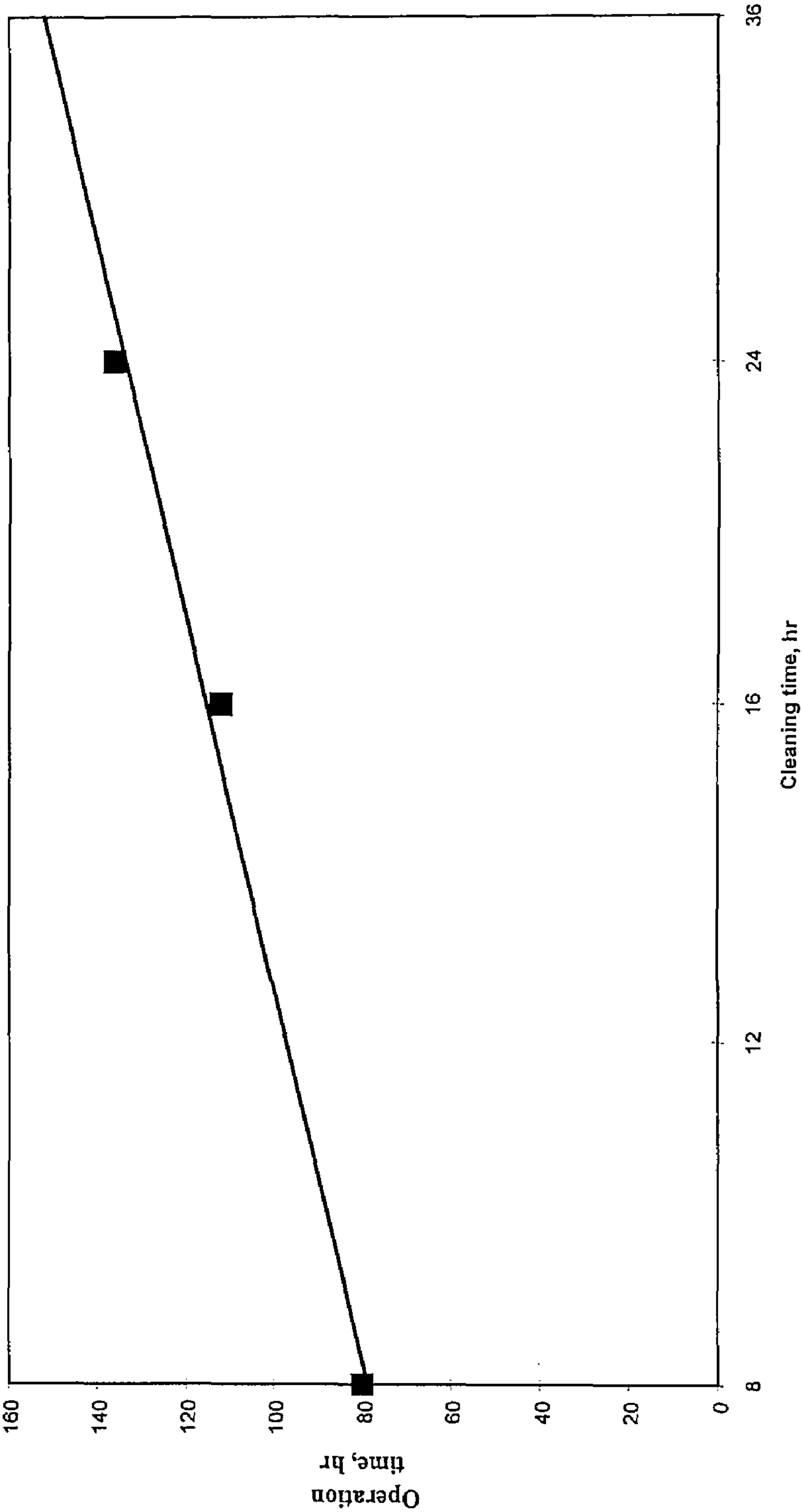


Fig. (4) Effect of cleaning time on operation time for 8 hours shift plants

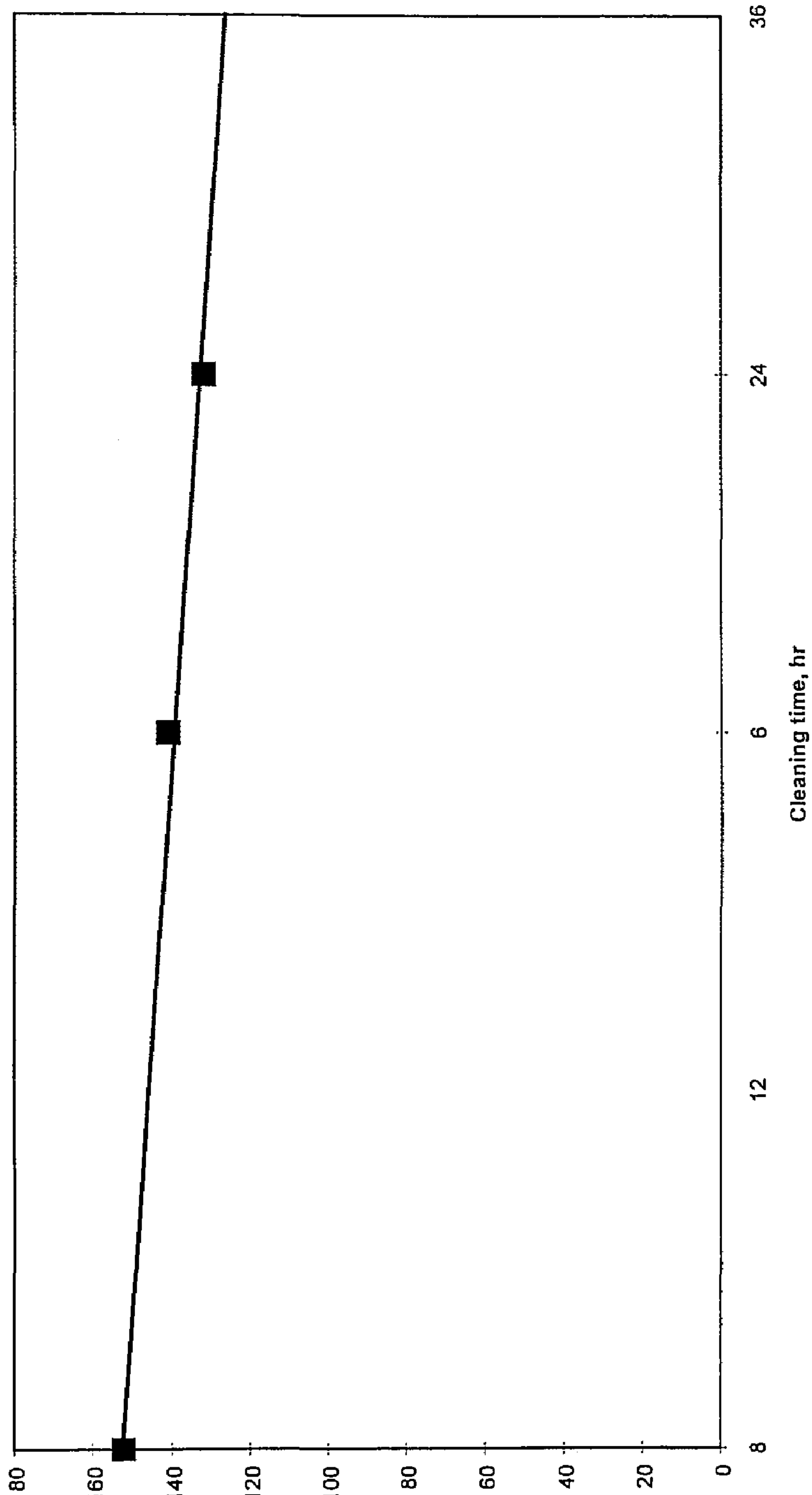


Fig. (5) Effect of cleaning time on minimum heat transfer coefficien for 8 hours shift plants

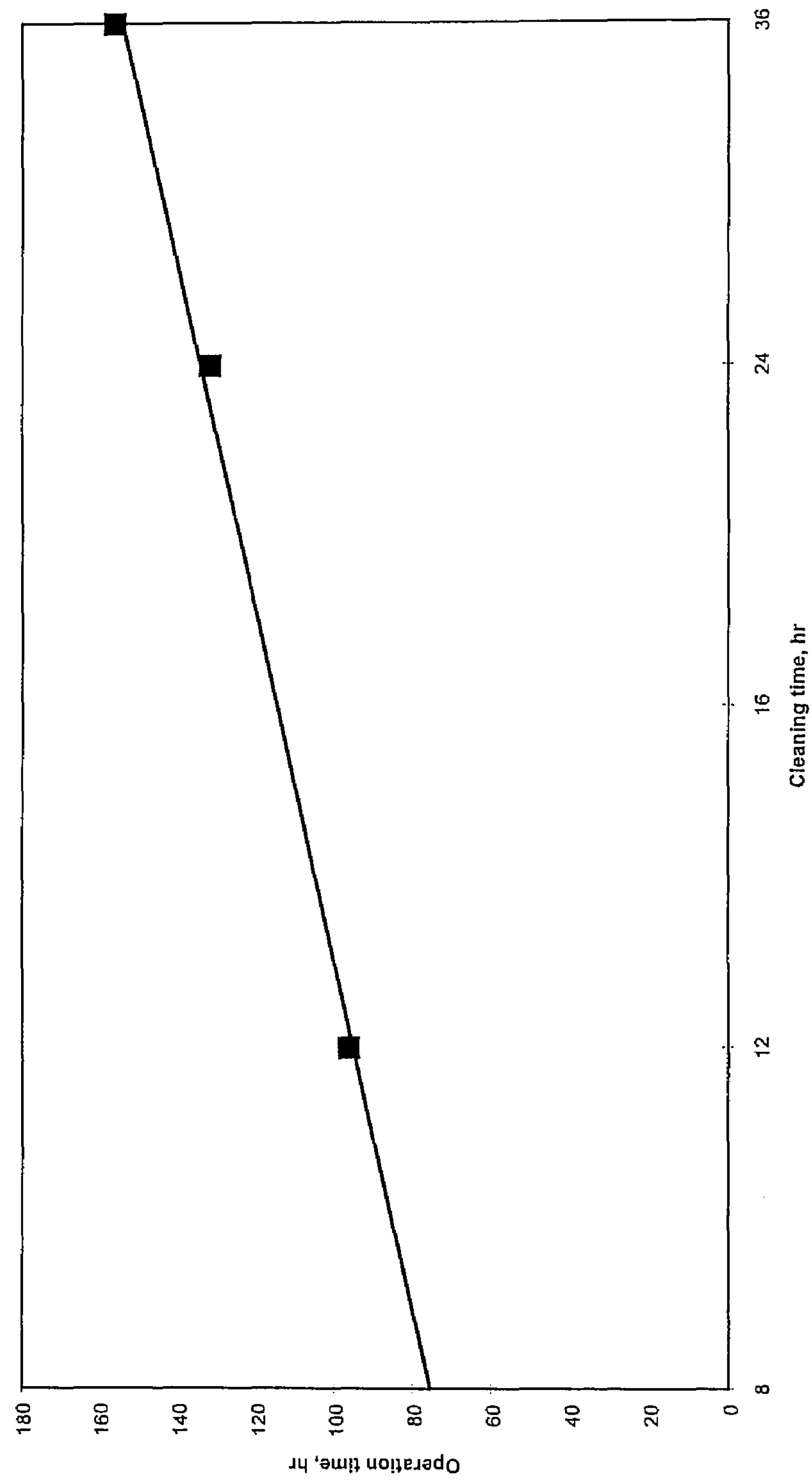


Fig. (6) Effect of cleaning time on operation time for 12 hours shift plants

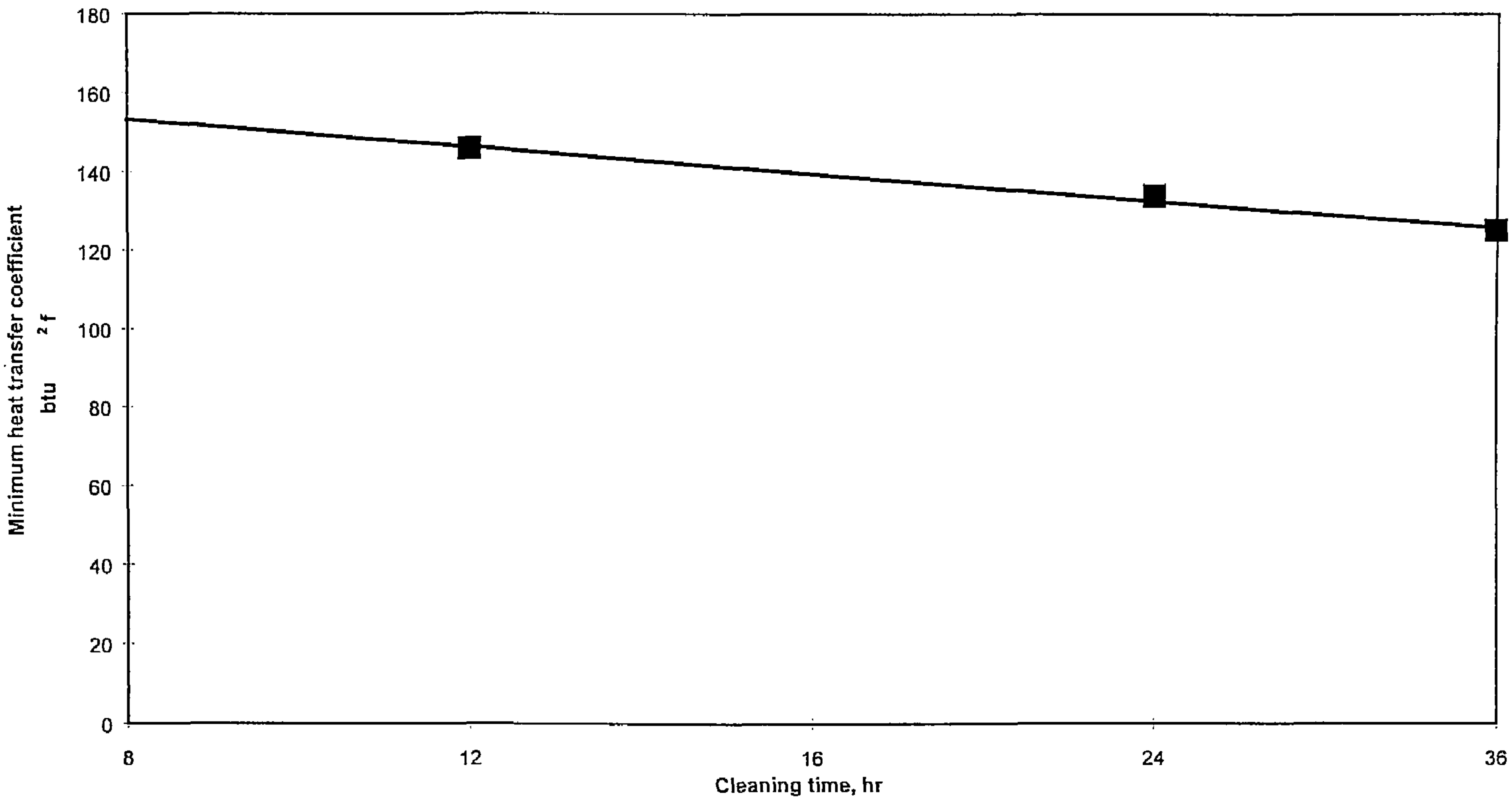


Fig. (7) Effect of cleaning time on minimum heat transfer coefficient for 12 hours shift plants