

A Study on the Diffuser Inlet Shape of Thermo Compressor for Multi Effect Evaporating System of Waste Water Treatment Plant

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ABSTRACT: Recently, the public interest in environment and the industrial wastes is not only increased but environmental regulation is becoming a key factor in a business administration and a factory operation. Therefore, it is a very important task to develop an efficient liquid treatment system satisfying a water quality standard because the liquid waste is the most difficult material to treat among industrial wastes. In existing treatment systems, industrial wastewater is treated usually by biological or chemical treatment method. However, operating conditions of these treatment methods are difficult and show a limitation for treating hard-decomposing organic matter. In particular, the wastewater treatment is highly important gilding process for surface treatment or cleaning process in semiconductor industry because the produced wastewater from these fields includes heavy metal material or toxic material. To treat this, it is known that a vacuum evaporating system is the best method. The vacuum evaporating system usually adopts a multi effective evaporating method and thermo-compressor to increase the system efficiency. The compressing process is performed by the thermo-compressor. Hence, the system efficiency strongly depends on the thermo-compressor entrainment ratio. This CFD study was performed to increase the thermo-compressor entrainment ratio by changing the diffuse convergence angle in various loading conditions

keywords: Thermo-compressor, Vacuum evaporator, Waste water treatment, Entrainment ratio

NOMENCLATURE

Alphabetic

A : Cross sectional area (m²)

C_p: Specific heat at constant pressure (J/kg.K)

CDL : Converging duct length (m)

D : Diameter (m)

ER : Entrainment ratio

F : Force (N)

GOR : Gain output ratio

h : Specific enthalpy (J/kg)

k : Turbulent kinetic energy (m²/s²)

M : Mach number

$\dot{m}$: Mass flow rate (kg/s)

NXP : Nozzle exit position

P, p : Pressure (Pa, bar)

r : Radial distance (m)

T : Temperature (K)

t : Time (s)

V : Volume (m³)

v : Velocity (m/s)

Greek Letters

α : Angle of converging duct (°)

ρ : Density (kg/m³)

μ : Viscosity (kg/m.s)
 ε : Turbulence dissipation rate (m^2/s^3)
 Subscripts
 d : Discharge
 eff: Effective
 m : Motive
 r : Radial direction
 s : Suction
 Superscripts
 * : Critical

1. INTRODUCTION

The vacuum evaporating system is often used to concentrate heavy metals and sludge ingredient consecutively in wastewater because evaporating water in a vacuum state is highly effective, which means that the water is evaporated in the temperature below 100°C . Furthermore, the boiling temperature will be more decreased if the degree of a vacuum is increased. In addition to it, the lower boiling temperature has the advantage to keep a scale from growing. This system requires much energy if the evaporating quantity is increased because the heat energy is basically needed for evaporating water.

The vacuum evaporating system usually adopts a multi effective evaporating method and thermo-compressor to increase the system's efficiency. In this paper, the performance of a thermo-compressor employed is analyzed in multi effect evaporating system treating wastewater.

The aim of this study is to reveal the maximum discharge pressure and entrainment ratio of the thermo-compressor and subsequently pave the way for more innovative and optimum thermo-compressor designs. The organization of this thesis was divided in two main parts, i.e. experiment and computational fluid dynamics. In the experimental investigation, five different convergence angles of a diffuser inlet were investigated to study the influence of operating pressure and suction pressure on the thermo-compressor performance.

2. EXPERIMENT DEVICE

2.1 Performance test apparatus

In this study, the pilot plant is 5 stages multi effect vacuum evaporating system with thermo-compressor, rated 350 ton/day. The test facility is shown in Fig.1, a steam ejector vacuum system, main condenser, three feed water pre-heater, steam boiler, fresh water pump and associated data acquisition system for temperature, pressure and flow rate.

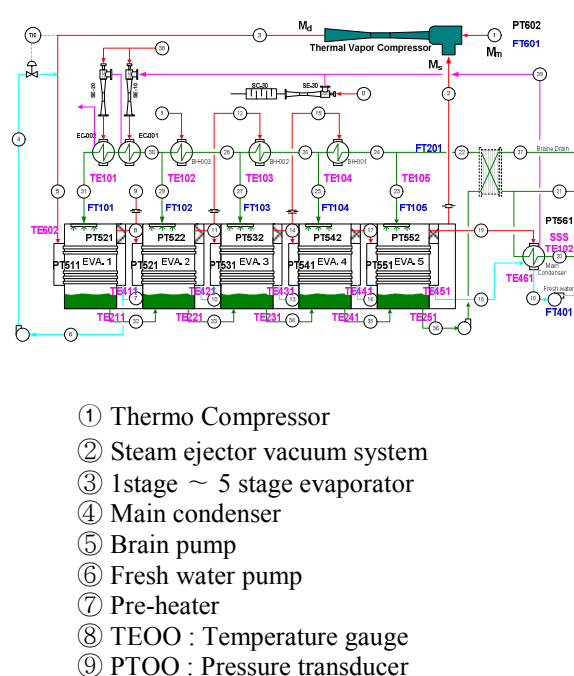


Fig. 1 Schematic diagram of experimental apparatus

Fig. 2 shows conventional thermo-compressor. Table 1 lists the dimensional data of the experimental thermo-compressor. The jet nozzle throat diameter is 38.0 mm; outlet diameter is 90.8mm; diffuser throat diameter is 204.0 mm; its length is 714.0mm that is 3.5 times of diffuser throat diameter. Fig.3 shows the thermo-compressor installed for multi effect wastewater treatment.

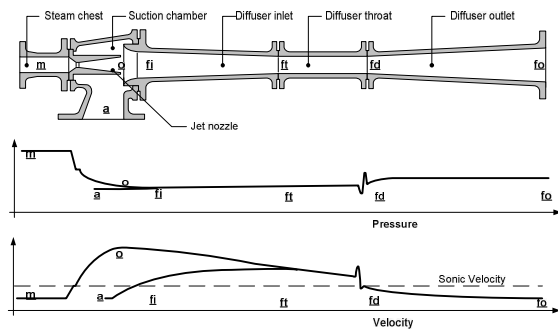


Fig. 2 Schematic diagram of thermo-compressor and variation of pressure and velocity distribution.

Table 1 Dimension of experimental thermo-compressor

	Unit	Dim.	Remark
Nozzle throat diameter	ϕ	38.0	
Nozzle outlet diameter	ϕ	80.8	
Diffuser inlet diameter	ϕ	251.0	
Diffuser throat diameter	ϕ	204.0	
Diffuser outlet diameter	ϕ	438.0	
Nozzle enlargement angle	$^{\circ}$	7.5	
Diffuser convergence angle	$^{\circ}$	1.0	
Diffuser enlargement angle	$^{\circ}$	3.5	
Diffuser inlet length	mm	1,345.0	
Diffuser throat length	mm	704.0	
Diffuser outlet length	mm	1,898.0	



Fig. 3 Experimental thermo-compressor

2.2 Performance test method

The suction pressure of the thermo-compressor is 0.08 barA (saturation temperature 41.5 $^{\circ}$ C) at the 5th effect evaporator, which determines steam ejector vacuum system, and discharge pressure is 0.20 barA (saturation temperature 65.0 $^{\circ}$ C).

First, suction pressure was controlled by flow rate of wastewater, which is supplied to a condenser and controls a suction flow rate of the steam ejector vacuum system. The suction pressure was controlled from 0.06 barA (saturation temperature 37 $^{\circ}$ C) to 0.12 barA (saturation temperature 50 $^{\circ}$ C).

Also, the motive steam pressure was controlled from 2.7 barA to 1.3 barA. That is, the supplied flow rate of motive steam was from 1.59 ton/hr to 0.86ton/hr.

3. EXPERIMENTAL RESULT AND DISCUSSION

Fig.4 and Fig.5 show pressure distribution of thermo-compressor wall for each driving stream flow rate and the change of a suction When the suction pressure is fluctuated, the internal pressure distribution of the thermo-compressor was completely different if the suction pressure becomes excessively lower than the design pressure.

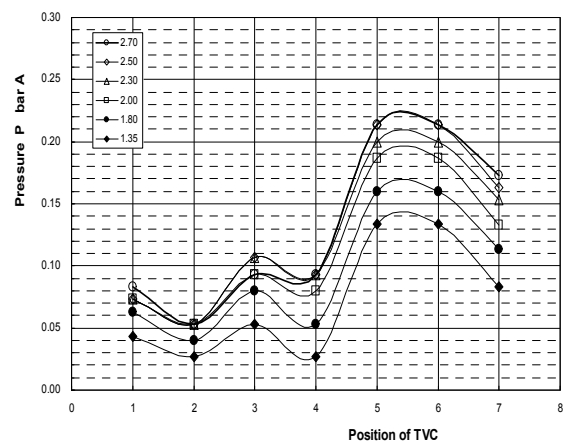


Fig. 4 Pressure distribution along the thermo-compressor wall for various motive steam pressure

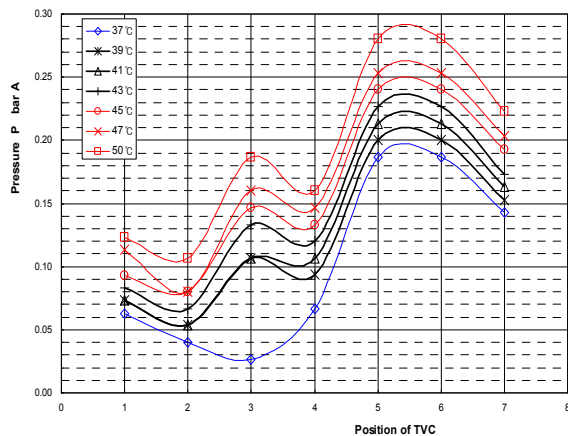


Fig. 5 Pressure distribution along the thermo-compressor wall for various suction pressure

In Fig.6, the entrainment ratio is gradually raised to the design pressure by the suction pressure gouging. But, the entrainment ratio shows a frugal tendency in contrary if the suction pressure rises than the design pressure. Service conditions of thermo-compressor is appearing as occasion and sequence that is gotten from service conditions through engineering data that execute numerical analysis from boundary condition differ a little.

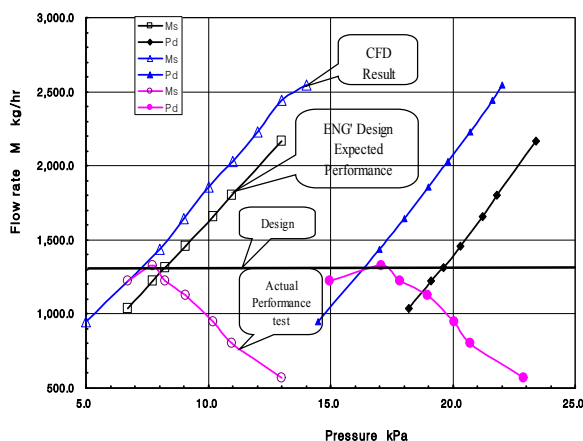


Fig. 6 The influence of suction pressure on the entrainment ratio

Fig.7 shows the available energy can know dwindling thing because temperature difference of 1 stage evaporator and 5 stages

evaporator decreases to 15.7 to 12.3 as suction pressure of thermo- compressor rises gouging.

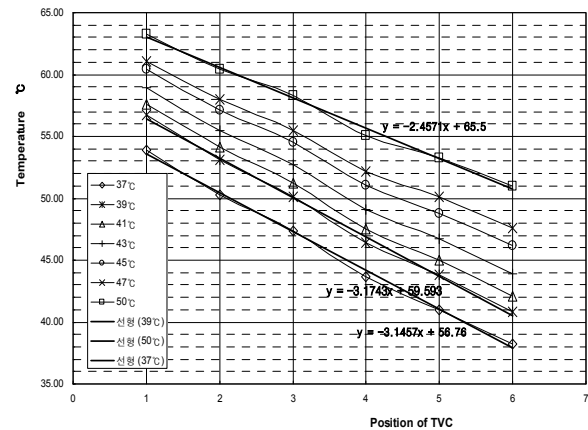


Fig. 7 Temperature distribution on the evaporator

Fig. 8 shows the entrainment ratio by CFD analysis results according to the convergence angle of diffuser inlet, suction pressure is 0.13 barA, 0.16 barA, 0.19 barA respectively, and the convergence angle was most suitable performance in 0.0 ~ 4.5 °

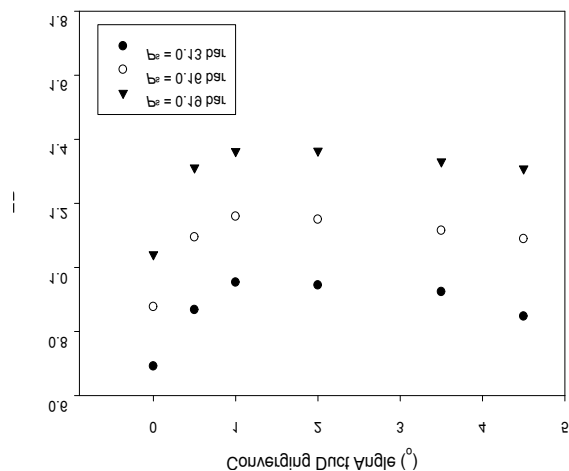


Fig. 8 The entrainment ratio of thermo-compressor at various convergence angle

Fig. 9 shows the entrainment ratio by experimental results according to the motive steam pressure, which is 1.8 barA to 3.5 barA, and the motive steam was most suitable performance in 2.7 barA.

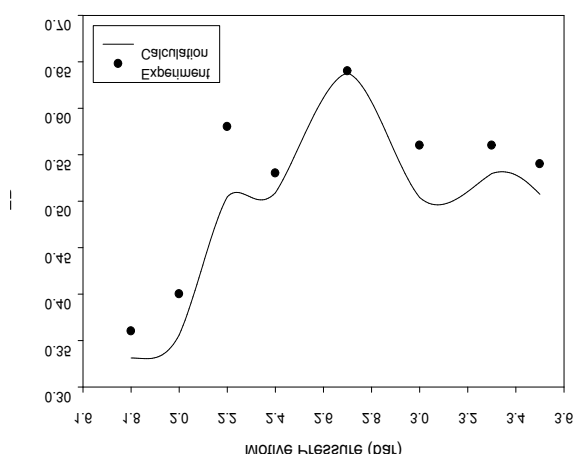


Fig. 9 The entrainment ratio of thermo-compressor at various motive pressure

Table 2 shows the case that the motive steam pressure keeps 2.7 barA with controlling the temperature (suction pressure) via entrainment ratio, and suction pressure keeps 0.08 barA with controlling the motive steam pressure via entrainment ratio. As shown in Table 2, the entrainment ratio is greatly changing according to the motive steam pressure.

Table 2 Experimental results of thermo-compressor

Ts	PT601	TE601	TE411	TE421	TE431	TE441	TE451	TE461	En. Ratio	Product
37°C	2.70	64.0	53.9	50.3	47.4	43.7	41.0	38.2	0.77	14.30
39°C	2.70	67.3	56.7	53.1	50.1	46.4	43.8	40.8	0.83	14.80
41°C	2.70	70.0	57.6	54.1	51.2	47.5	45.0	42.1	0.77	14.40
43°C	2.70	71.8	58.9	55.5	52.7	49.1	46.7	43.9	0.71	14.00
45°C	2.70	76.8	60.4	57.1	54.5	51.1	48.8	46.2	0.59	13.20
47°C	2.70	79.0	61.1	58.0	55.5	52.2	50.1	47.6	0.50	12.50
50°C	2.70	82.9	63.3	60.4	58.3	55.1	53.3	51.0		11.50
Pm	PT601	TE601	TE411	TE421	TE431	TE441	TE451	TE461	En. Ratio	Product
2.70	2.70	0.173	0.163	0.123	0.093	0.103	0.083	0.053	0.85	15.00
2.50	2.50	0.153	0.153	0.123	0.093	0.113	0.083	0.043	0.84	13.80
2.30	2.30	0.153	0.143	0.113	0.093	0.113	0.083	0.033	0.78	12.60
2.00	2.00	0.133	0.133	0.113	0.093	0.103	0.073	0.033	0.82	11.00
1.80	1.80	0.063	0.040	0.080	0.053	0.160	0.160	0.113	0.89	10.00
1.35	1.35	0.043	0.027	0.053	0.027	0.133	0.133	0.083	0.90	7.45

4. Conclusions

In this study, the experimental and CFD studies are performed to entrainment ratio characteristics in the multi effect evaporating system, and to verify the validity of the design of test facility with rated capacity of 350 ton/day. Experimental results were compared with CFD calculation results of the thermo compressor. It was found that the various range of entrainment ration of thermo compressor on test facility

showed a good agreement with CFD calculation results. Particularly, for the entrainment ratio by analysis results according to the convergence angle of diffuser inlet, suction pressure is each 0.13 barA, 0.16 barA, 0.19 barA, and convergence angle is most suitable performance in 1.0 ~ 2.0 °. From experimental results, the entrainment ratio was found 0.85.

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