# THEORETIC ENERGY CONSUMPTION OF NONFERROUS METALS BY VACUUM DISTILLATION[①]

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**ABSTRACT** The expressions of heat of evaporation for metals at different temperatures were deduced from Clausius-Clapeyron equation and the total change of enthalpy. Those of Pb, Cd and Zn were calculated. Results showed that theoretic energy consumption decreased a little with the decrease of evaporation temperature, which can be used to determine the energy demand while these metals are distilled at different process temperatures and pressures.

**Key words** energy consumption heat of evaporation vacuum distillation

## 1 INTRODUCTION

Vacuum metallurgy has some advantages such as low process temperature, high evaporation temperature and good separation efficiency.

It has become the main means of reforming conventional nonferrous metals metallurgy and the recovery of nonferrous metal wastes.

Since it is still considered that vacuum metallurgy is an expensive process and that the energy consumption of which is too high for it to be widely used in nonferrous-metals metallurgy, it is necessary for us to calculate the heat of evaporation and theoretic energy consumption of nonferrous metals at different evaporation temperatures.

## 2 CALCULATION METHODS

Generally speaking, heat of evaporation increases with the decrease of evaporation temperature (pressure).

When evaporation temperature $T_v$ is less than the normal boiling temperature $T_b$, according to Clausius-Clapeyron equation, we have the following equation:

$$\frac{dp}{dT} = \frac{\Delta H_v}{T(V_g - V_l)} \tag{1}$$

because $V_g \gg V_l$, $V_g - V_l \approx V_g$, so:

$$\frac{dp}{dT} = \frac{\Delta H_v}{TV_g} \tag{2}$$

where $\Delta H_v$ is the heat of evaporation, J/g; $p$ is the pressure, Pa; $V_g$ is the mole volume of gas; $V_l$ is the mole volume of liquid; $T_v$ is the evaporation temperature, K; $T_b$ is the normal boiling temperature, K.

We then further assume the vapor to be ideal and replace $V_g$ by $RT/p$, as a result, Eqn. (2) becomes:

$$\frac{dp}{dT} = \frac{\Delta H_v}{RT^2} \tag{3}$$

The heat of evaporation at temperature $T_v (T_v < T_b)$ can be deduced:

$$\Delta H_v(T_v) = \Delta H_v(T_b) \frac{T_v^2(\mathrm{d}\ln p/\mathrm{d}T)T_v}{T_b^2(\mathrm{d}\ln p/\mathrm{d}T)T_b} \tag{4}$$

Theoretic energy consumption $Q$ is the total change of enthalpy from 298 K to $T_v$. When $T_v < T_b$,

$$Q = \int_{293}^{T_m} C_{p,s}(t)\mathrm{d}t + \Delta H_m + \int_{T_m}^{T_v} C_{p,l}(t)\mathrm{d}t + \Delta H_v(T_v) \tag{5}$$

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When $T_v > T_b$,

$$Q = \int_{293}^{T_m} C_{p,s}(t)dt + \Delta H_m + \int_{T_m}^{T_b} C_{p,l}(t)dt + \Delta H_v(T_b) + \int_{T_b}^{T_v} C_{p,g}(t)dt \quad (6)$$

where $C_{p,s}$, $C_{p,l}$, $C_{p,g}$ are the specific heat of solid, liquid and gas respectively, J/g·K; $\Delta H_m$ is the heat of fusion, J/g; $R$ is gas constant.

## 3 RESULTS AND DISCUSSION

As an example, we calculated the heat of evaporation and the theoretic energy consumption of Pb, Cd and Zn at vacuum. Their thermodynamic data[1-3] are as follows.

For lead:

$$C_{p,s} = 0.113 + 4.68 \times 10^{-5} T \quad (298\sim600\,K) \quad (7)$$

$$C_{p,l} = 0.155 - 1.33 \times 10^{-5} T \quad (600\sim1\,400\,K) \quad (8)$$

$$C_{p,g} = 0.123 + 9.69 \times 10^{-6} T \quad (1\,400\sim2\,013\,K) \quad (9)$$

$$\Delta H_m = 23.01$$

$$\Delta H_v(T_b) = 854.89$$

$$\lg p_i^0 = -10\,130/T_v - 0.985 \lg T_v + 13.285 \quad (10)$$

For cadmium:

$$C_{p,s} = 0.1975 + 1.09 \times 10^{-4} T \quad (298\sim594\,K) \quad (11)$$

$$C_{p,l} = 0.264$$

$$C_{p,g} = 0.185$$

$$\Delta H_m = 56.91$$

$$\Delta H_v(T_b) = 889.11$$

$$\lg p_i^0 = -5\,919/T_v - 1.257 \lg T_v + 14.412 \quad (12)$$

For zinc:

$$C_{p,s} = 0.336 + 1.727 \times 10^{-4} T \quad (298\sim692\,K) \quad (13)$$

$$C_{p,l} = 0.4855 - 3.528 \times 10^{-5} T \quad (692\sim1\,122\,K) \quad (14)$$

$$C_{p,g} = 0.318$$

$$\Delta H_m = 112.58$$

$$\Delta H_v(T_v) = 1\,593.59 - 0.1433\,T_v \quad (15)$$

$$\lg p_i^0 = -6\,620/T_v - 1.225 \lg T_v + 14.465 \quad (16)$$

where $p_i^0$ is the vapor pressure of the pure metals, Pa.

Using the above data of $\Delta H_v(T_b)$, $T_b$, $(d\ln p/dT)T_v$ and $(d\ln p/dT)T_b$ derived from pressure equation, we got the heat of evaporation of Pb, Cd and Zn at different temperatures. The calculated results are shown in Table 1.

**Table 1 Heat of evaporation of lead, cadmium and zinc at vacuum**

| $T_v$ /K | $\Delta H_{v,Pb}$ /J·g$^{-1}$ | $\Delta H_{v,Cd}$ /J·g$^{-1}$ | $\Delta H_{v,Zn}$ /J·g$^{-1}$ |
|---|---|---|---|
| 773 | 884.0 | 917.6 | 1 842.7 |
| 823 | 884.1 | 911.9 | 1 835.5 |
| 873 | 883.9 | 906.3 | 1 828.4 |
| 923 | 883.5 | 901.0 | 1 821.2 |
| 973 | 882.7 | 895.6 | 1 814.1 |
| 1 023 | 881.8 | 890.4 | 1 806.9 |
| 1 073 | 880.7 | 889.1 | 1 799.7 |
| 1 123 | 879.5 | 889.1 | 1 792.6 |
| 1 173 | 878.2 | 889.1 | 1 785.4 |
| 1 180 | 878.1 | 889.1 | 1 784.4 |

Expressing $\Delta H_v$ as the function of $T_v$, we have:

For lead:

$$\Delta H_{v,Pb} = 905.9 - 0.02452\,T_v \quad (17)$$

For cadmium:

$$\Delta H_{v,Cd} = 1\,001.0 - 0.1077\,T_v \quad (18)$$

For zinc:

$$\Delta H_{v,Zn} = 1\,593.59 - 0.1433\,T_v \quad (19)$$

Using the above data, we can integrate Eqns. (5) and (6) to obtain the theoretic energy consumption of Pb, Cd and Zn. The calculated results are listed in Table 2.

Theoretic energy consumption has a little decrease with the decrease of evaporation temperature. There is no or little waste gas while crude metals are refined by vacuum distillation. Vacuum system is used to maintain the pressure of system only. Therefore, the energy consumption of vacuum system is small. The total energy consumption under vacuum may not be greatly larger than that in atmos-

Table 2 Theoretic energy consumption of evaporation of lead, cadmium and zinc by vacuum distillation

| $T_v$ /K | $Q_{Pb}$ /J · g$^{-1}$ | $Q_{Cd}$ /J · g$^{-1}$ | $Q_{Zn}$ /J · g$^{-1}$ |
|---|---|---|---|
| 773 | 975.8 | 1 094.7 | 2 160.5 |
| 823 | 983.1 | 1 102.2 | 2 176.2 |
| 873 | 990.1 | 1 109.9 | 2 191.8 |
| 923 | 996.8 | 1 117.7 | 2 207.3 |
| 973 | 1 003.2 | 1 125.6 | 2 222.8 |
| 1 023 | 1 009.4 | 1 133.6 | 2 238.1 |
| 1 073 | 1 015.4 | 1 141.7 | 2 253.4 |
| 1 123 | 1 021.2 | 1 150.1 | 2 268.6 |
| 1 173 | 1 026.9 | 1 158.5 | 2 283.6 |
| 1 180 | 1 027.8 | 1 159.5 | 2 285.7 |

phere distillation. Because process temperature at vacuum is greatly lower than that under atmosphere pressure, it will reveal lots of advantages in future application.

## 4 SUMMARY

The expressions of heat of evaporation for metals at different temperatures were deduced from Clausius-Clapeyron equation and the total change of enthalpy. Those of Pb, Cd and Zn were calculated. Results showed that theoretic energy consumption decreased a little with the decrease of evaporation temperature, which can be used to determine the energy demand while these metals are distilled at different process temperatures and pressures.

## REFERENCES

1 Nesmeyanov A N. Vapour Pressure of the Chemical Elements. Amstedam: Elsevier Publishing Company, 1963.

2 Ye Dalun. A Handbook of Inorganic Thermochemistry Data (in Chinese). Beijing: Metallurgical Industry Press, 1979.

3 Xu Caidong, Liu Tong, Wang Dacheng. Physical Chemistry of Zinc Metallurgy (in Chinese). Shanghai: Science and Technology Publishing House, 1979.

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