Risk Management of Chlor-Alkali Industry based on CVaR

Dong Chen, Tomohiro Murata

***Abstract*—In recent years, risk management has increased widely from financial institutions, regulators and portfolio managers, such as Value-at-Risk (VaR) and Conditional Value-at-Risk (CVaR). Using this model can measure the risks in uncertainty factors and decisions the production planning for a plant. Now, China's Chlor-Alkali industries had to face the grim situation. Comparing with other industries, production planning of Chlor-Alkali industries is more complicated. Especially for an imbalance between demand and response in Chlor-Alkali products market, how to reduce the loss is a major problem for the policymaker. In the current market environment, the plant must make a viable decision while considering the risks from market. That required a market risk analysis. In this paper, we proposed a risk measurement model with a restrictive condition which can optimize the production while taking uncertainties into consideration, such as material price, electricity price, product price, order changes, and especially the restriction of liquid chlorine inventory. Eventually, a case study is submitted to demonstrate the feasibility of the developed model, and verify the effectiveness of the algorithm employed.**

***Index Terms*—uncertainty inventory restriction Conditional Value-at-Risk**

I. Introduction

Comparing with other countries, although China's Chlor-Alkali industries started relatively backward, there also some great progress has been achieved after 30 years of development. At the end of 2010, the full capacity of China's caustic soda production China's had already reached the first place in the world. But rapid progress also brought serious problems. Especially in recent years, under the influence of irrational industrial structure and vicious competition, China's Chlor-Alkali plant is in the face of the grim situation. Now that, China's Chlor-Alkali industries have entered a period of adjustment.

Now most of the Chlor-Alkali industry research were concentrated on the producing technology [1] and pollution control [2]. In paper [3], it proposed a circular economy that can be utilized to reduce the environmental pollution. And paper [4] suggested a risk management approach in chemical industry supply Chain, but this research didn't mention the loss in risk factors.

Nevertheless, all researchers ignore a problem that there are fluctuations in actual markets. Here we take the market between 2015-2016 as an example, caustic soda products prices rose as 45%, while the price of liquid chlorine products decreased about 70%. In the current market environment, Chlor-Alkali plant must make a viable decision while considering the risks from the market. That requires a risk analysis of complex markets. Another issue we should take into consideration is that due to the accident risk of the liquid chlorine, there is the restriction on the liquid chlorine inventory if the limit has been exceeded meanwhile the plant must discontinue the whole production line.

In recent years, risk management is increasing widely from financial institutions, regulators and portfolio managers, such as Value-at-Risk (VaR) and Conditional Value-at-Risk (CVaR). The greatest advantage of VaR is that it can describe the estimated loss of a portfolio with a given confidence level in a value [5]. However, paper [6] indicated that it is not a coherent risk measure since it fails to the subadditivity and does not consider the losses over the value. Because of the limitations, a new risk measurement has been put forward that is CVaR. It is superior to VaR as a risk measure because it measured the expected loss than the VaR at a specified confidence level [7]. In paper [8], based on recent data in the actual stock market, the optimal portfolio is calculated by computing the ratio of the minimum risk CVaR. Paper [9], applied this method in the electricity market and established a risk evaluation model.

In this paper, we will consider the restriction of liquid chlorine inventory and the uncertainties caused by risk factors, such as raw material prices, market prices, electricity prices, the delivery ratio of orders and so on. Here we proposed a risk measurement model with a restrictive condition which can optimize the production planning for Chlor-Alkali plant and ensure normal production.

II. Some characteristics in Chlor-Alkali industry production

Here we take ion-exchange membrane electrolysis as an example [10]. The Chlor-Alkali process produces caustic soda,

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Dong Chen is a master student in Graduate school of Information, Production and System, Waseda University, Japan. (e-mail: cireck@akane.waseda.jp).

Tomohiro Murata is a professor in Graduate school of Information, Production and System, Waseda University, Japan. (e-mail: t-murata@waseda.jp).

chlorine and hydrogen through the electrolysis of sodium chloride solution.

$$2NaCl + 2H_2O = 2NaOH + H_2\uparrow + Cl_2\uparrow \quad (1)$$

Through t chemical equation, we could know the particularity of the products of Chlor-Alkali industry. Usually, 1kg caustic soda production is accompanied by the 0.89kg of chlorine and 0.025kg of hydrogen. In some literature, it is called the balance industry [11]. According to the Equation (1), if the production planning of the caustic soda is determined in *i*th month, the consumption of the crude salt and the production of the chlorine could be determined at the same time. We assume the following as this formula.

$$Q^P_{na}(i) = r_1 Q^P_{nacl}(i) = r_2 Q^P_{cl}(i) \quad (2)$$

Where the $Q^P_{na,}$, Q^P_{cl} represent *i*th month production of caustic soda and chlorine, and Q^P_{nacl} represent *i*th consumption of the crude salt, and r_1, r_2 are the rate of the production. Actually, caustic soda products can be divided into 32% solution, 50% solution, and solid caustic soda. In this paper, we take 32% solution caustic soda solution production to discuss (50% and solids can be obtained from it). Similarly, liquid chlorine as the chlorine production was made because it was used in marketing. There is no consideration of hydrogen production because its output is low and the market price is stable.

Compared with the individual production planning, it has become a more complex plan for Chlor-Alkali plant to consider the market demand and prices of the two products separately. Caustic soda products are in short supply because of its wide range of uses in marketing. However, liquid chlorine market is just the opposite. Taking one product of caustic soda solution Sodium Hydroxide 32% as an example, in Chinese market the cost is about 180 US$ per t, and market price is as high as 350 US$ per t (on 100% basis price). Unfortunately, liquid chlorine products are about 160 US$ per t in cost and 15US$ per t in market sales, and the price may be lower at disposal.

In the current profitable market state of caustic soda products, decision makers may then choose a relatively high-risk production plan in order to obtain more benefits, but they often have to consider a serious problem of dealing with the excessive loss of liquid chlorine. And another problem of the production planning is influences under the uncertainty factors.

III. UNCERTAIN FACTORS FROM MARKET

A. cost impact factors

Generally, the costs of Chlor-Alkali plant include fixed costs and variable costs [12]. Fixed costs include equipment depreciation, transportation, labor fee, water fee and pollution treatment fee. And the variable costs are mainly considered the raw material costs and the electricity costs. The cost of the *i*th month can be expressed as:

$$C(i) = C_{nacl}(i) + C_{el}(i) + C_{fix}(i) \quad (3)$$

Where the $C_{nacl}(i)$ represents salt costs of the *i*th month, $C_{el}(i)$ represents *i*th month electricity costs, $C_{fix}(i)$ represents *i*th month fixed costs. This paper focuses on the variable costs which include crude salt and electricity costs. Presently, the framework contract is primarily applied in the procurement of raw materials crude salt. But the prices will still have a fluctuation in the market. In order to simulate these uncertain effects, here we use P_r to represent changes of the salt prices, and assume P_r follows the normal distribution to represent changes of the crude salt price which means value μ_r and standard deviation σ_r. If the crude salt price $P_r(i)$ in *i*th month can be simulated, then the cost of crude salt would be:

$$C_{nacl}(i) = Q^p{}_{nacl}(i) \times P_r(i) \quad (4)$$

The other variable cost is electricity price. Especially for high consumption industries, the price changes will have a huge impact [13]. Existing literature shows that the Geometric Brownian motion could better simulate seasonally changing trends [14]. So here we use the geometric Brownian motion to describe the electricity prices changes.

The formula is as follow:

$$P_t = P_0 \times \exp((\mu - \frac{\sigma^2}{2}) + \sigma w_t) \quad (5)$$

The electricity price is denoted by P_t at time t with the expected return by μ, and the standard deviation by σ if the initial electricity price P_0 was given, we can use Equation (5) to calculate the price at each time. About w_t is a Brownian motion. μ and σ are constants and can be estimated through statistical analysis of historical data.

According to production electricity consumption rate r_3 the cost of electricity could be calculated as:

$$C_{el}(i) = r_3 \times Q^p{}_{na}(i) \times P_{el}(i) \quad (6)$$

C_{el} and P_{el} are the electricity cost and electricity price of the *i*th month.

B. order and price factors.

Here we will discuss the uncertain factors of the market and their effects on product price and order. In this paper, caustic soda products and liquid chlorine products will be discussed separately due to their different market situations. Usually, marketing of caustic soda products includes two ways, order contract and trade market. Most part of the production is selected to deliver orders, while the other part of the production is sold in the trade market. The amount of caustic soda order Q^d_{na} and price P_{na} of order contract are relatively stable, but the trade market is subject to considerable changes. The prices in trade market P'_{na} may be higher than the order price, but sometimes lower. Here we also use a normal distribution P'_{na} (μ_{na}, σ_{na}) to describe the price changes in the market.

In contrast to short supply of caustic soda product market, liquid chlorine products market is not so optimistic. In the overall current tight market, its orders and prices are lower than the caustic soda products. Because of the total inventory constraints, the price may be reduced to sell the redundant part. Compared with the order price P_{cl}, the disposal price P'_{cl} has a highly unstable, and sometimes there exists a negative price. That means the plant will pay extra money to the disposal of remanding products that usually happen in the market. Here we

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also use a normal distribution P'_{cl} (μ_{cl}, σ_{cl}) to describe the price changes.

However, there still exist some uncertainties in the implementation of the contract, transport capacity and quality of production. In order to represent the order change, here we assume that both the amount of orders Q_{dna} and Q_{dcl} follows a normal distribution with mean values μ_{dna}, μ_{dcl}, and standard deviations σ_{dna}, σ_{dcl}.

Through the above discussion, we can get the sales of *i*th month caustic soda and liquid chlorine.

$$S_{na}(i) = Q^{d}{}_{na}(i) * P_{na}(i) + (Q^{p}{}_{na}(i) - Q^{d}{}_{na}(i)) * P'_{na}(i) \tag{7}$$

$$S_{cl}(i) = Q^{d}{}_{cl}(i) * P_{cl}(i) + Q'_{cl}(i) * P'_{cl} \tag{8}$$

Where $S_{na}(i)$ and $S_{cl}(i)$ are the two product sales in the *i*th month.

IV. FORMULATION OF THE MODEL

First, we will describe the constraints of liquid chlorine inventory in the production planning. Fig 1 show the new liquid chlorine inventory process. The formula is

$$Q^{cl} inv(i) = Q^{p}{}_{cl}(i) - Q^{d}{}_{cl}(i) - Q'_{cl}(i) \tag{9}$$

Where the $Q'_{cl}(i)$ represents the monthly amount of disposal and $Q^{cl}{}_{inv}(i)$ shows the monthly production of new liquid chlorine inventory.

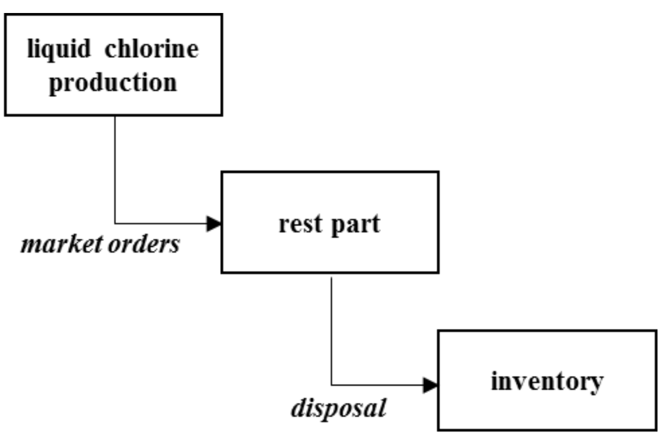

Fig 1 liquid chlorine inventory

In order to guarantee the normal production of the factory, the liquid chlorine inventory of 12 months must less than the inventory capacity Q_{cap}.

$$\sum^{12} Q^{cl}{}_{inv}(i) \le Q_{cap} \tag{10}$$

Through the above analysis, let $R(x, y)$ be the revenue function of the Chlor-Alkali plant. Where $x_T = [Q_{pna}(1), Q_{pna}(2), \ldots Q_{pna}(12)]$ mean the production plan and it is a decision vector. $y_T = [P_r, P_{el}, Q_{dna}, Q_{dc}, P'_{na}, P'_{cl}]$ is the random vector. The function as follows:

$$R(x, y) = \sum^{12} S_{na}(i) + \sum^{12} S_{c1}(i) - \sum^{12} C(i) \tag{11}$$

So, we define the loss function of the Chlor-Alkali plant would be $-R(x, y)$. In general, CVaR calculation is complicated, in paper [7] introduced an approximate method by adding a new function $F_\beta(x, a)$ to solve this problem. The expected value of that $F_\beta(x, a)$ could be approximated by sample mean. And the sampling calculation of $F_\beta(x, a)$ can be assumed by $\hat{F}_\beta(x, a)$.

We introduce the variables $Z_k = (-R(x, y) - \alpha)^+$ (k=1,2,…,N) for simplification. The CVaR model for Chlor-Alkali plant has been established as described in formula (12)-(21).

Objective:

$$\min \hat{F}_\beta(x, \alpha) = \min(\alpha + \frac{1}{N \times (1-\beta)} \sum_{k=1}^{N} Z_k) \tag{12}$$

Subject to:

$$\sum^{12} S_{na}(i) = \sum^{12} \{Q^{d}{}_{na}(i) * P_{na}(i) + (Q^{p}{}_{na}(i) - Q^{d}{}_{na}(i)) * P'_{na}(i)\} \tag{13}$$

$$\sum^{12} S_{cl}(i) = \sum^{12} \{Q^{d}{}_{cl}(i) * P_{cl}(i) + Q'_{cl}(i) * P'_{cl}\} \tag{14}$$

$$\sum^{12} C_{nacl}(i) = \sum^{12} \{Q^{p}{}_{nacl}(i) \times P(i)\} \tag{15}$$

$$\sum^{12} C_{el}(i) = r_3 \sum^{12} \{Q^{p}{}_{na}(i) \times P_{el}(i)\} \tag{16}$$

$$\sum^{12} C(i) = \sum^{12} C_{nacl}(i) + \sum^{12} C_{el}(i) + \sum^{12} C_{fix}(i) \tag{17}$$

$$E\left(\frac{\sum^{12} S_{na}(i) + \sum^{12} S_{cl}(i)}{\sum^{12} C(i)}\right) - 1 \ge e \tag{18}$$

$$\sum^{12} Q^{cl} inv(i) = \sum^{12} Q^{p}{}_{cl}(i) - \sum^{12} Q^{d}{}_{cl}(i) - \sum^{12} Q'_{cl}(i) \tag{19}$$

$$\sum^{12} Q^{cl}{}_{inv}(i) \le Q_{cap} \tag{20}$$

$$Z_k = (-R(x, y) - \alpha)^+ \ge 0 \tag{21}$$

Where i =1,2, … ,12; k=1, 2, … N; Equation (13) -(14) described the sales of two productions in 12 months. Equation (15) -(17) described the cost of one year. Equation (18) is the expected return of the Chlor-Alkali plant and e stand for the lower bound of the expected return rate. (where $0 \le e \le 1$) Equation (19) -(20) are the constraints of liquid chlorine inventory. $(-R(x, y) - \alpha)^+$ mean max $(-R(x, y) - \alpha, 0)$. Using the Monte Carlo Sampling method to generate a sample of the random vector y, and calculated the CVaR with a linear programming problem.

V. CASE STUDIES AND DISCUSSION

A. Data of the Case

First, we use the geometric Brownian motion to simulate the electricity price trends for 12 months form historical data at Fig.2. The initial electricity price as 0.1162 US$ per kWh. Generally, it is difficult to forecast the electricity price accurately. But to predict its future trend according to the historical price data and economic trend is feasible. Therefore, this paper tries to simulate the changing trends of price, rather than to find methods to accurately predict the price.

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Here we take the capacity of caustic soda production Q^{p}_{na} 200,000 ton one year the Chlor-Alkali plant as an example. The monthly average of caustic soda order is 15,000 tons, and the average of liquid chlorine order 11,00 tons. Liquid chlorine inventory capacity 200t and the initial value is 0, and crude salt quantity is enough. With the current market price [15], here we set the caustic soda order price as 350 US$ per t, liquid chlorine products order price as 15US$ per t, crude salt price as 35 US$ per t, liquid chlorine disposal price as 5 US$ and the fixed cost is 20 US$ per t. r_1, r_2 and r_3 is1.46,0.89 and 2600Kwh/t. The other random parameters in the model are generated through Monte Carlo method with100 samples and Parameters Values are shown in Table I Calculation the CVaR in different expected return rates by MATLAB.

Table I Parameters Values

Para	Value	Para	Value US$
σ^{d}_{na}	0.15 x10^{4} ton	σ_{na}	35 US$
σ^{d}_{cl}	0.11 x10^{4} ton	σ_{cl}	2 US$
Q_{cap}.	200 ton	σ_{r}	3 US$

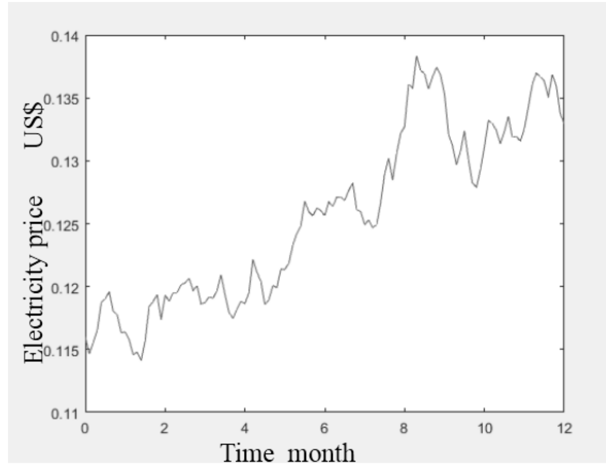

Fig.2. electricity price changes in 12 month.

B. Results and discussion

Based on the values of the parameters given in Table 1 with the Monte Carlo Sampling Method. We calculated results of optimization of production planning in Fig.3 and sensitivity analysis of CVaR and expected return rate was shown in Fig.4.

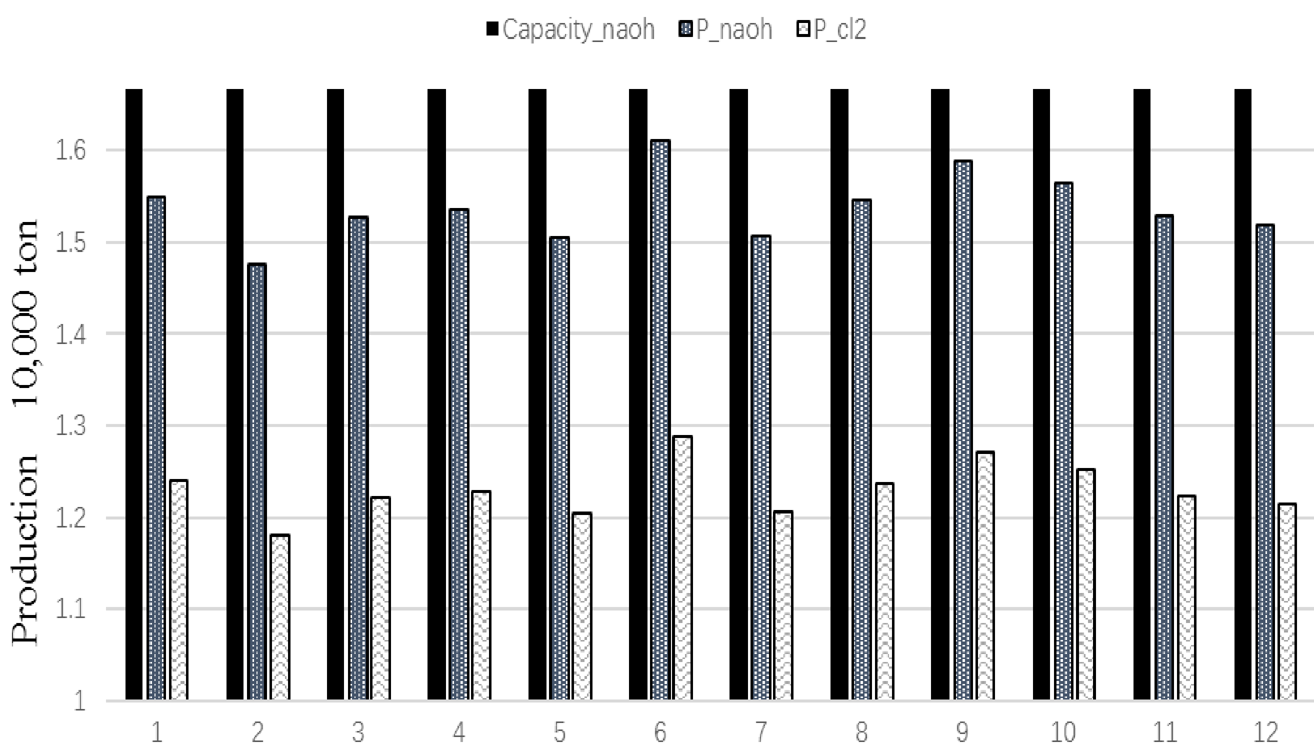

Fig.3 Optimization result of production planning

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The results show that here is a lower production when the cost increases. A high production needs to consider the liquid chlorine disposal of the cost reduction. The plant should determine a minimum safe yield to preclude running out of supply due to fluctuation in orders.

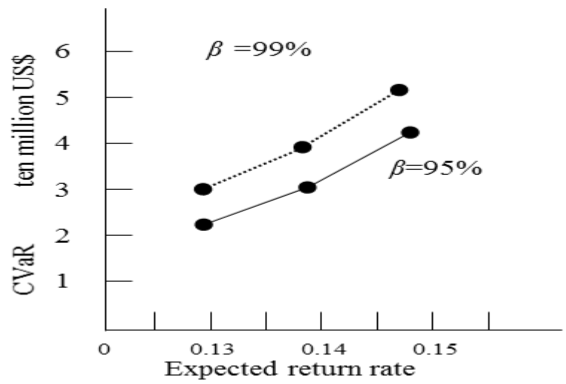

Fig.4. CVaR in different confidence levels
with different expected return rates.

Fig.4 shows the calculation results of CVaR with different confidence levels with different expected return rates. Through the analysis, we can realize that the two curves are increasing. The increasing expected return rate will inevitably lead to an increase in CVaR. At the same expected return rate, and the CVaR value increases as the confidence level increases. This is also consistent with the current market and the validity of the model is verified.

VI. Conclusion

We should take a risk measurement to consider the uncertain factors bring risks of plants. In the competitive market, making production planning under different demand and supply of the two products is extremely important to Chlor-Alkali plants. In this paper, we proposed a restrictive condition programming CVaR model to optimize the production planning while taking uncertainties into consideration, such as material price, electricity price, product price, order delivery, and especially the restriction of liquid chlorine inventory. A case study is presented to demonstrate the feasibility of the developed model, and verify the effectiveness of the algorithm employed. Also, how to accurately reflect the changes in market prices will be the future work in research.

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