A New Model for the Consumption and Control of Petroleum Resources in China

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Abstract **— Using logistic modelling techniques, in this paper we analyze the optimization management of petroleum resources using a new mathematical model in which we study: i) the total output of petroleum, ii) total discovered reserves, iii) unexploited petroleum reserves, and iv) the total demand of petroleum. The consumption model of petroleum resources and the response model of petroleum exploitation are established respectively.**

Keywords - Logistic model, petroleum resources, mathematical model, differential equations.

I. INTRODUCTION

Petroleum resources is nonrenewable, the demand for petroleum is more than 1/3 of total energy demand, and is the main motive force of economic growth. As a kind of energy resources, petroleum is an important strategic material in the national economy and the people's livelihood. The consumption of China's petroleum resources will continue to maintain sustained and stable growth for a long period of time in the future as China is developing. Thus, it is a vital subject to study the reasonable exploitation and utilization of petroleum resources[1-3]. This paper mainly analyzes the optimization management of petroleum resources from the point of view of mathematical modeling.

II. CURRENT SITUATION OF PETROLEUM INDUSTRY IN CHINA

At present, China is not only a big petroleum producer but also a big petroleum consumer in the world. And China is a promising petroleum gas market, being a very important part of the petroleum industry worldwide. The amount of recoverable petroleum resources in China is 2.12×10^{11} ton, and the amount of China's possible petroleum resources is 1.086×10^{12} ton, According to the late evaluation results of China's petroleum gas resources, the exploration being at the middle stage. The petroleum consumption in China over nearly twenty years is shown in figure 1.

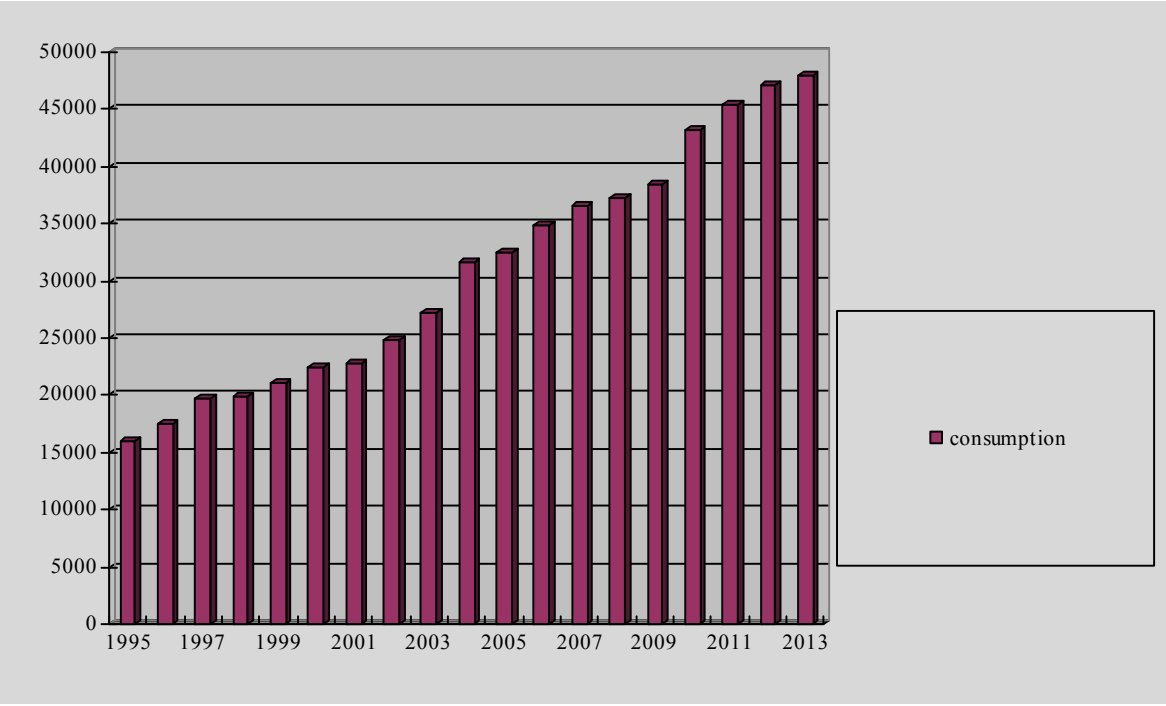

Figure 1 The petroleum consumption in China over nearly twenty years
Data source: National Bureau of Statistics (unit: million tons)

III. A STUDY ON THE MODEL OF PETROLEUM RESOURCE CONSUMPTION IN CHINA

It is assumed that the production and consumption of petroleum resources are always balanced, not considering the time delay caused by reserves, transportation and sales. Meanwhile, it is assumed that the newly discovered petroleum reserves and production meet Logistic curve according to the relevant research results and statistical data [4-5].

Logistic model is expressed as $\frac{dx}{dt} = rx(1-\frac{x}{K})$, here its initial conditions is: $x\Big|_{t=t_0} = x_0$, where x is the amount of petroleum consumption, t is time, r is parameters of petroleum consumption growth, $r > 0$, and K is the greatest amount of petroleum consumption.

By solving Logistic model, we can obtain $x = \frac{K}{1+(\frac{K}{x_0}-1)\exp(-r(t-t_0))}$

Here we discuss law of four key factors (total output, total discovered reserves, unexploited petroleum reserves, total demand) varying with time. By analyzing the relationship between four above mentioned factors, we can establish differential equation models, where the relevant parameters of each model can be determined by historical data fitting.

A. Model analysis and hypothesis

Suppose that there is no time delay between petroleum exploitation and consumption, that is, the demand function satisfies the law of supply and demand in economics, where the supply amount is inversely proportional to the price, and the demand amount is directly proportional to the price. $t = 0$ representing the starting year 2000 in models. Suppose that petroleum cannot be artificially synthesized in short term.

B. The establishment and solution of the model

Here four functions are given: $W(t)$ stands for accumulative discovered petroleum amount at time t moment, $Q(t)$ stands for accumulative exploited petroleum amount at time t moment, $R(t)$ stands for demand amount at time t moment, $P(t)$ stands for petroleum amount that is not exploited at t times.

Let $M_0(2.12\times10^{11})$ be the upper limit of China's total petroleum resources, the annual growth velocity of accumulative discovered amount slows down as the exploitation deepens in later period. The annual discovered amount is zero, when the accumulative discovered amount reaches the upper bound M_0, and the growth velocity of the accumulative discovered amount is stimulated by demand amount. The more the demand, the more the detecting technology and devices are put into operation, followed by the growth of the annual discovered amount. Here establish Logistic model, that is, the growth factor is determined by demand amount with content M_0.

$$\frac{dW}{dt} = kRW(1-\frac{W}{M_0}) \qquad (1)$$

Where constant k is used for balancing dimension with date, and k can be obtained by historical data fitting. Logistic model is also suitable for the estimation of accumulative exploited amount, since exploited petroleum amount is always smaller than discovered amount. Logistic model of exploited amount $Q(t)$ with content $W(t)$ is as follows,

$$\frac{dQ}{dt} = cRQ(1-\frac{Q}{W}) \qquad (2)$$

Where constant c is used for balancing dimension (and numerical value) with date, and c can be obtained by historical data fitting.

The unexploited petroleum reserves satisfy $P(t) = M_0 - Q(t)$

Differentiate the above equation, we can obtain:

$$\frac{dP}{dt} = -\frac{dQ}{dt} = -cRQ(1-\frac{Q}{W}) \quad (3)$$

According to the economic law of the relationship between the supply and the demand, the price is in inverse proportion to the supply, the demand is in direct proportion to the price. For the simplicity of the problem, suppose the supply is in direct proportion to the demand, that is $R(t)\Big/\frac{dQ}{dt} = b$, b is ratio coefficient (4)

Summing up the above analysis, we obtain the following system of differential equations:

$$\begin{cases} \dfrac{dW}{dt} = kRW(1-\dfrac{W}{M_0}) \\ \dfrac{dQ}{dt} = cRQ(1-\dfrac{Q}{W}) \\ \dfrac{dP}{dt} = -cRQ(1-\dfrac{Q}{W}) \\ R(t)\Big/\dfrac{dQ}{dt} = b \end{cases}$$

If the accumulative discovered amount $W(t)$, the accumulative exploited amount $Q(t)$, the annual demand amount $R(t)$ and the unexploited amount $P(t)$ in the past several years can be found in historical data, where $t \in [t_0, t_n]$ is the time of historical data collecting, then by Euler iteration method, we have

$$W(t_{i+1}) - W(t_i) + \varepsilon_i = \frac{dW(t_i)}{dt} = kR(t_i)W(t_i)(1-\frac{W(t_i)}{M_0})$$

$i = 0,1,\cdots,n-1;\varepsilon_i$ is the error caused by the random property of the actual data, here the estimate of the parameters k is to solve the following program problem.

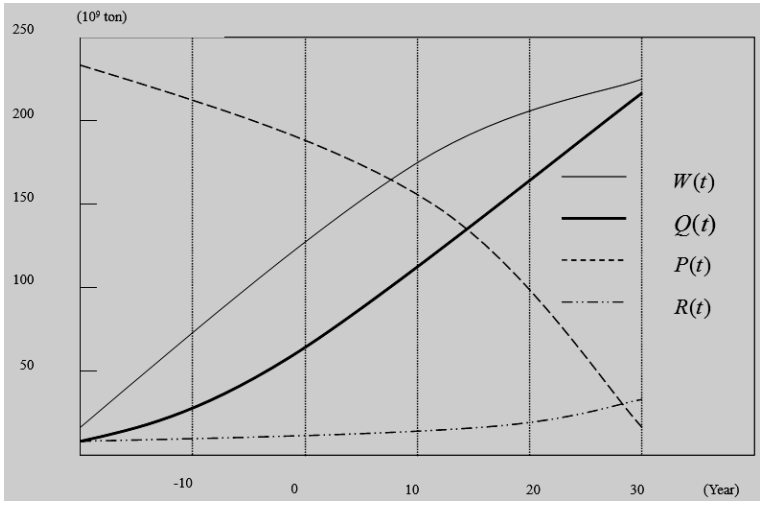

Figure 2 Four curves varying with the time

$$\min z = \sum_{i=0}^{n-1} \varepsilon_i^{\,2}$$

Similarly, solving b, c is the same as that of k. After determining k, b, c, solving the above system of differential equations numerically, we can obtain four curves varying with the time as the initial value and parameters are given, as is shown in figure 2.

The differential functions of the above curves have intuitive meaning: at time t, Q' is exploited amount in

unit time, R' is demand amount in unit time, W' is discovered amount in unit time.

IV. RESPONSE MODEL OF CONTROLLING PETROLEUM EXPLOITATION

The parameter c in the above differential equations has two meanings. First, c represents the technical level of petroleum exploitation. The bigger the value of c, the higher the technical level of petroleum exploitation, and the more rapid the response to the demand, thus causing the increase of exploitation velocity. Second, c stands for the policy response to the demand. The smaller the value of c, the stronger the intensity of policy regulation and controlling. By policy leading and guiding, taking all kinds of energy saving measures, readjusting the petroleum price, the sensitivity of the supply to the price is lessened, and the dependence on the supply is also lessened, which causes the decrease of petroleum exploitation amount [6-7].

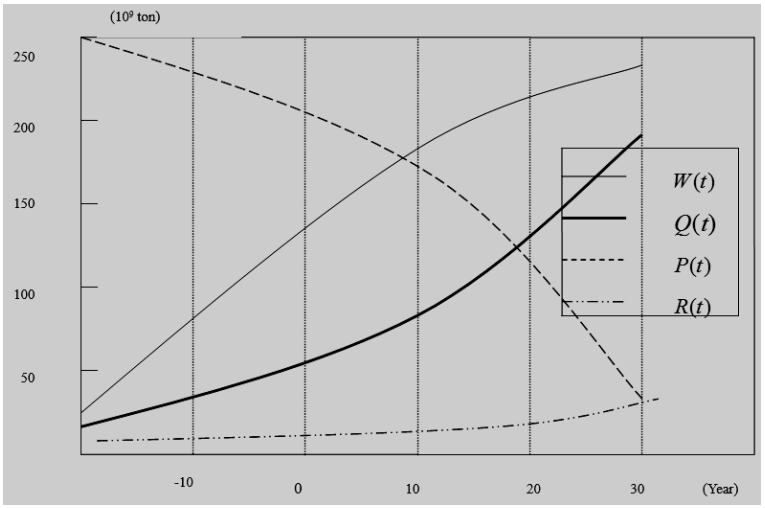

Figure3. Four curves of main factors varying with time after controlling petroleum exploitation

It is supposed that the dependence on petroleum resources is lessened by developing substitute energy, the petroleum price is regulated and controlled by the policy, the sensitivity of the production to the demand is lowered, that is, the value of c is brought down to 60% that of the year 2010 and keeping a period of time, the corresponding mathematical model is as follows:

$$\begin{cases} \dfrac{dW}{dt} = kRW(1-\dfrac{W}{M_0}) \\ \dfrac{dQ}{dt} = c(t)RQ(1-\dfrac{Q}{W}) \\ \dfrac{dP}{dt} = -c(t)RQ(1-\dfrac{Q}{W}) \\ R(t)\Big/\dfrac{dQ}{dt} = b \\ \begin{cases} c(t) = c_0, t < 10 \\ c(t) = 0.6c_0, \text{else} \end{cases} \end{cases}$$

Also using Euler iterative method, the model can be solved. Four curves of main factors varying with time are as follows (in figure3).

It can be seen that the petroleum exploited amount drops off sharply after the exploitation controlling measures are taken, thus holding up economic development, and causing economic recession. On the contrary, if the value of the parameters c is raised, the growth of the economy can be promoted in short term, while quickening the consumption of petroleum resources.

V. CONCLUSION

Petroleum resource is limited and cannot be regenerated. China's petroleum industry should be sustainable. The cooperation of China with other countries is worth studying [8-10]. All countries should develop and use new substitute energy, realizing the stable transition of resources utilization and the harmonious development of social economy finally.

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