OPTIMAL CONTROL OF FLUID CATALYTIC CRACKING UNIT

***JiangQingyin CaoZhikai Caijie Zhouhua**
Department. Of Chemical Engineering. Xiamen University,
Xiamen 361005, China
*****_Email: xdceds@xmu.edu.cn_
ChenZiluan WangChenglin ChenXiliang DengMingbo
China Petroleum&Chemical Corporation Guangzhou Branch
GuangZhou 510726,China

Abstract: This paper discusses the problem of on-line optimal control of FCCU. First a new optimal control scheme is put forward. Then some key problems to make up this optimal control system and the solving scheme are discussed. Finally, the on-line industrial running results of this system are given.

Keywords:Optimal Control, Adaptive,On-line, Process.

1. INTRODUCTION

FCCU (Fluid Catalytic Cracking Unit) is one of the most important units in oil refinery. It also occupies very significant position in the refinery because of its economic benefits. So how to improve the operation level of this unit is paid a close attention by the circle of petrochemical works. No doubt one of the effective methods is to implement its online optimization and advanced control.

The Department of Chemical Engineering of Xiamen University has cooperated with Guangzhou Oil Refinery of China Petroleum&Chemical Corporation Guangzhou Branch to develop the FCCU optimal control system. This system has done a good job since it was put into practice at the beginning of 1995. This paper will introduce this system and its application

2. FCCU PROCESS FLOW

FCCU consists of three subunits: Reactor-regenerator section, main fractionator and absorption stabilization section. The reactor-regenerator section is the most important sector in these three subunits. In which the fresh feed is atomized by superheated steam, injected into riser, and combined with high temperature (650-750) catalyst which came from regenerator. The catalyst and the hydrocarbon vapors flow up the riser and the cracking reaction is processed at the meantime. In order to prevent over reaction and improve the distribution of the product, a quick separation is adopted in the outlet of the riser. After separation, the catalyst is known as spent catalyst. At first the spent catalyst is dropped into stripping section of the reactor. Then the spent catalyst is transported to regenerator by the slope-pipe. The reacted vapor products are sent to the main fractionator where various boiling point fractions are withdrawn such as distillate, light cycle oil (LCO), heavy cycle oil (HCO) gasoline and diesel, etc. Parts of oil that are not converted by the crack-reaction are sent back to riser reactor according to some ratio. The diesel is out of FCCU directly but the gasoline must be sent to absorption- stabilization section and then the stabilized gasoline is formed.

Regenerator is the spot where the coke of the spent catalyst is burnt off in contact with air and the activity of the catalyst is recovered. The regenerated catalyst is then recalculated back to the bottom of the riser reactor though the regenerated-slope-pipe. After that, the regenerated catalyst flows into the riser by rising steam and used again in the riser. The flux of the cycle catalyst can be controlled in the two slope-pipes where the valve location of the single slide valve is tuned. By changing the valve location of the double slide valve, which is equipped in the gas pipe of the regenerator, the pressure of the regenerator can be controlled.

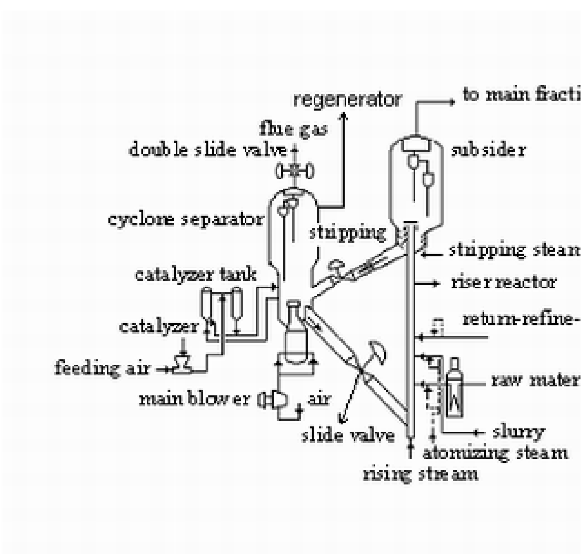


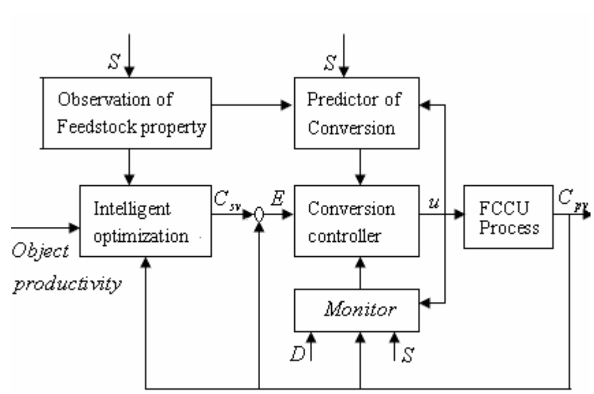
Fig 1. FCCU process flow

3. OPTIMAL CONTROL SCHEME

Traditional optimal control scheme in FCCU is primarily based on the control of reaction temperature. But it is the degree of reaction that influences the whole unit and the products distribution mostly. Reaction temperature doesn’t represent the degree of reaction as it is affected by many factors, so is not suitable to be used as the control variable. So the traditional scheme is an indirect method actually. To solve this problem, YuanPu(1992) put forward a scheme using reaction heat as the main control variable. The basis of it is that the reaction heat may serve as a direct measurement to the degree of reaction under the condition of unchangeableness of property of feedstock. So it doesn’t fit for those units with frequently alterative feeds on property. Moreover, immeasurability of reaction heat is also a great difficulty to make the scheme going on.

Our developed optimal system is a two cascade closed-loop system which takes the conversion percentage as the optimal variable because it is the direct measurement to the degree of reaction and can be calculated online from the products distribution of FCCU. A neural network is used to predict this conversion percentage online and at real-time because there may be a large time-delay to calculate the conversion percentage. Based on this, closed-loop optimization is achieved by the uses of online observation for feeds property and adaptive intelligent optimal method.

Two cascade closed-loop optimal control schemes are shown as Fig 2:



Where C_{pv}: conversion percentage

C_{sv}: optimum set-point of conversion percentage

S: operation information

D: fault diagnosis information

E: error of controller

u: controller output

Fig 2. optimization scheme

3.KEY PROBLEMS AND SOLVING METHODS

3.1 Online observation of property of feedstock

As much oil refinery in southward China use much export oil from various countries, the oil property can not be kept stable. So it is of great importance for the optimal control system to make a quick response to the change of oil. However, the real-time analytic data on the feed oil is lacking because of the poor real-time and online analytic means. To solve this problem, we use the reaction model and the temperature distribution of riser reactor to estimate the property of the feedstock(Jiang Qingyin,1995).

$$YX = \frac{K_{CO}}{K_{AO}} H_{cr} = F\left(\beta_o, \Delta T_{rai}, T_{rai}\right)$$

Simplify the reaction model, a parameter is gotten as:

Where K_{CO}, K_{AO}, K_{Cr} are coke reaction rate constant, cracking reaction rate constant and cracking heat respectively. Define YX as feed factor. As YX only has relationship with the property of feedstock and the catalyst activation, it can serve as an expression for the property of oil. The right size of the equality above is a function relationship formed by riser temperature, temperature difference and catalyst-oil ratio which are all measurable or calculable. Therefore YX can be estimated online at real-time.

We can see that YX mainly indicates the heat needed by the feedstock in cracking reaction. The larger YX is, the more cracking heat is needed, and the feed oil is more difficult to be cracked.

3.2 Prediction of conversion percentage

As mentioned above, the core of conversion percentage control is its real-time prediction. To solve this problem, a BP neural network is adopted and has made a good result.

BP neural network is the most extensive kind of neural networks to be applied. It consists of an input layer La, several hidden layers (usually one layer) and an output layer Lc. Nonlinear mapping relationship between input variables and output variables is built up by learning. For its structural characteristic it has good fault-tolerant capacity which is very important in the industrial process.

For the industrial online application, the BP models must have a strong generalization capability. A number of papers had discussed the generalization problem by discussing the structure and the learning algorithm of ANN, but recently, some researchers have paid attention to the problem of training samples. It has been pointed out that the basic reasons affecting the generalization capability of neural network are quality, quantity and the representation ability of the training samples.

In this Optimal Control system, we introduce a Self-organizing structure (JiangQingyin,Caijie and Cao Zhika,2002) to build up an input-output pattern base which use the continuous sample data of industrial process and automatically screen out the inputs-outputs patterns with high quality and good representation ability. Using these patterns as training samples, we can obtain a BP model of good generalization capability.

Real-time running result has shown that this BP predictor has a quite high accuracy on prediction. As shown in Fig 3, fluctuations of conversion percentage are exactly predicted. What needs to be explained clearly is that in this case the weights matrix of BP neural network was calculated some months ago when it was used. Although there are many changes in operative condition, prediction is accurate, as comes from the good adaptive capacity of this BP neural network.

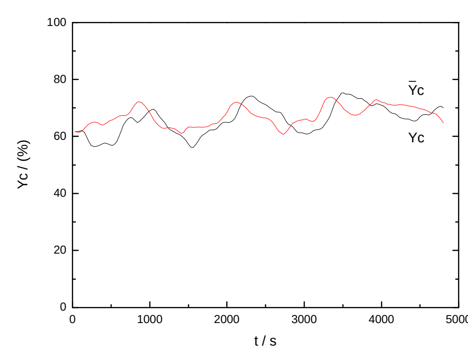


Fig 3. Online prediction of conversion percentage by BP network

3.3 Model identification-free adaptive control

Model identification-free adaptive control (MFA) is a kind of adaptive control proposed by Marsik and Strejc(J.Marsik V.Strejc,1989) which needs not process model also needs not on-line identification of model parameters. This method only needs the error of process value and the expected value in industrial process, thus can form an adaptive closed-loop control system with good dynamic characteristic. Because of the advantages such as little calculating amount, easy to carry out and strong robustness, it is very suitable for the advanced control in industrial process. But this theory can't cope with the process with large time-delay. So in our optimal control system, a predictive algorithm is introduced and a self-searching algorithm aiming at to solve the problems of inaccurate estimation on delay time and predictive error has been developed(Jiang Qingyin,1997). The improved controller works well, as shown in Fig 4. In where the C_{sv} is the optimum set-point of conversion percentage and C_{pv} is the process value of conversion percentage, Δp is the main disturbance, u the output of controller and T the reaction temperature.

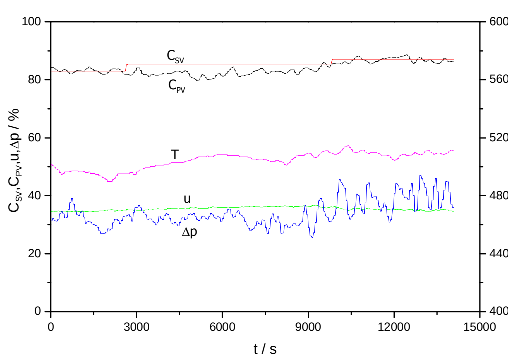


Fig 4. Online MFA control of conversion percentage

3.4 Fuzzy fault diagnosis

To assure the security of optimal control system, fault diagnosis is very important and necessary. Traditional expert system method doesn't quite fit for FCCU as it is very difficult to describe the faults in definite production rule. To make it more accurate and effective, we propose a fuzzy fault diagnosis method based on the theory of factor space (Caijie, Jiang Qingyin ,CaoZhikai and Zhouhua,2002). Besides, to solve the problem of improve on the adaptive capacity of fault diagnosis system, the method of variable weights based on the balanced function of factor spaces is introduced into the fault diagnosis system.

3.5 Adaptive intelligent optimal method

The traditional optimal method is based on the mathematic model. That is the optimal set- point is calculated by use of a series of mathematic methods. However, traditional method is hard to be realized for the on-line closed loop optimal system, because it is difficult to develop an accurate FCC mathematic model and correct it on-line. The expert system that rose in the 1980s has offered a kind of intelligent method for optimization. But it is necessary to build a knowledge base covers the whole states of process. Meanwhile it is important to keep the knowledge base adaptive as there has been a time-variation characteristic in most industrial process. For this reason, Jiang Qingyin and Shu diqian (Jiang Qingyin and Shu diqian,1993) proposed an on-line self-organizing learning method to construct a self-organizing knowledge base which can modify the knowledge automatically by itself, therefore to realize self-adaptation of the expert system.

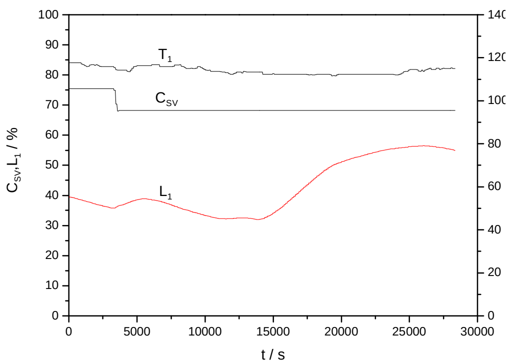
Based on it, a BP neural network is used to construct the reasoning model in order to adjust the set-point of conversion percentage in time when feedstock change. Because the building and correction of knowledge base and reasoning model are both going on automatically online, this enables a good adaptive capacity and robustness of optimal system for realizing the closed-loop optimization.

4. RUNNING SITUATION OF THE OPTIMAL CONTROL SYSTEM

This system had already been put close-loop running for years and achieved good results. After long time running, the optimal control system has shown some characteristics:

1. Security of close-loop is guaranteed. Because the optimal control system contains an integrated fault diagnosis system and adopts a series of safety measures to prevent accidents, such as instruments failure, sudden lost of power of master computer, the optimal system can all switch the closed-loop control to regular control of DCS immediately.

2. The performance of conversion percentage controller is good. It can follow the changes of given values, and has strong capacity of anti-interference, also the controller has an adaptive capacity to the change of property of feedstock and other operation condition.



Figur5 Close-loop running of optimal control system

3. This system is highly automatic and easy to use. As this optimal system has achieved closed-loop control in addition to the operational safety, the entire optimal process can be finished automatically without intervention by operators on the whole. Moreover, friendly user interface is supplied to make it easy to operate and maintain.

After being putting into effect, the optimal system has made several results as follow:

1. It makes the whole process more stable.

Degree of reaction becomes more steadily and the whole Unit of FCC includes the fractional and stabilizing systems are more steady and easier to be operated. For example, under the routine control, the liquid level of fractionating tower bottom waves up and down frequently to a high extent. While after the optimal control system working, generally flat liquid level has been maintained as degree of reaction has turned to be stable. This change has directly led to the decrease of related regulation and further the stability of whole fractionating tower. The operation state of the liquid level and the temperature of main fractionator on an eight-hour working period shift are shown in Fig 5. We can see that the stability of this unit is satisfactory.

2. The yield of light oil increases. Once we compared the effect of optimal control system and the old control system by put into operation in day shift with that of old control system and in night shift the optimal control system, under the condition of same quantity and same property of feedstock. The yield of light oil and the liquid in night shift increase obviously, as shown in Table 1. In addition, the yield of light oil increases about 0.6% according to workshop's statistics in a long time.

5. CONCLUSION

There is a hard work to achieve closed-loop optimal control in FCCU. Our proposed new optimization scheme has been verified to be feasible and effective by the practice in Guangzhou Oils Refinery. In this scheme, many technologies arising in the 1990s have been adopted. Especially it is the first time for some of these technologies to be applied successfully into so complicated catalytic cracking process.

During the development of this optimal control system, operators, technologists and managers in Guangzhou Oils Refinery gave us great support. Thanks them for their help to make it fulfill smoothly.

References

YuanPu(1992).*Petroleum Refining Sinica*, 23-27.

Jiang Qingyin(1995). On-line Observation for feedstock Property of Catalytic Crack Unit, *Journal of Xiamen University (Natural Science)*, **V34** pp960-964

Jiang Qingyin and Shu diqian(1993), Adaptive Realization of Expert System for Process Control and Operation, *Chinese Journal of Automation*, **V5** (1) pp.33.-37.

Jiang Qingyin,Caijie and Cao Zhika(2002), Self-Organizing Pattern Base and Its Application in the Complicated Industrial Process, *ICCA02, IEEE* ISBN: 0-7803-7413-4 p212- 215.

J.Marsik V.Strejc(1989), Application of Identification-free Algorithms for Adaptive Control, *Automatica*. **V25** (2), pp.273-277

Jiang Qingyin(1997), Predictive Algorithms of Identification -free Algorithms for Adaptive Control and Its Application, *Acta Automatica Sinica*, **V23** (1) pp.107.

Caijie, Jiang Qingyin ,CaoZhikai and Zhouhua(2002), Diagnosis of industrial process faults based on variable weight theory of factor space. *ICCA02, IEEE* ISBN: 0-7803-7413-4 p1125-1129.

Table 1: yields comparison

shift	Processing capacity (ton)	Light dirty oil	Yield of light oil	Yield of liquid
day	837.9	77.6	75.7%	82.2%
night	838.0	76.0	77.2%	84.1%

Note:

1. The products data were read by the process instruments which values were lower than real value in both cases.
2. Temperature control was used in day shift, and closed-loop optimal control was used in night shift.