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# Expert System Development on On-line Measurement of Sewage Treatment Based Process

**[1] Jianjun QIN, [2] Huajun GUO**
[1] Beijing University of Civil Engineering and Architecture,
No. 1 Zhanlanguan Rd., Xicheng District, Beijing 100044, P. R. China
[2] Hefei Xinan Patent agent co., LTD,
No. 1137 East Changjiang Rd., Heifei 230011, P. R. China
[1] Tel.: 86-10-68322420, fax: 86-10-68322420
[1] E-mail: Chinaqjj@163.com

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**Abstract:** This article puts forward a solution in which an instrument on-line automatic measurement and expert system process are optimized according to the complexity and great process dynamics of sewage treatment process. Firstly modeling has been set up with configuration sewage treatment process in which the process has been integrated into the computer software environment. Secondly certain number of water quality automatic monitoring instruments and sensor probes are set in the reaction tanks according to the needs of process changes and management. The data information acquired can be displayed and recorded at the real time. A human-machine integration expert system featuring computer automation management is developed for the base by one-off method thus to realize the intelligent and unmanned management. The advantages brought about from it can fill up the inexperience of the on-site management personnel and solve the contradiction between the water quality dynamics and difficulty in the process adjustment. *Copyright © 2014 IFSA Publishing, S. L.*

**Keywords:** Data acquisition, Expert system, On-line measurement, Process management, Sewage treatment process.

## 1. Introduction

There are lots of sewage treatment methods. Generally the ideal treatment results can be achieved only when they can operate properly with the processing steps of the several intercoupling according to the proper parameters [1]. The treatment results will be affected by the sewage quality condition and flow in the specific process implementation [2]. Therefore the operating parameters of process should be adjusted properly according to the water quality and flow so it is necessary to obtain the indicators such as water quality and flow parameters [3-5]. In the ideal condition, although the measurement of various sewage quality indicators can be completed with various monitoring instruments and tools, the measurement principle and acquisition periods of the detecting instruments can be different and the water quality parameters can be relatively great even to the location of same treatment tank, so it is so hard to obtain more real time information, which results in the difficulty in implementing the process that directs the sewage treatment accurately [5, 6]. Automatic monitoring and control equipment can be applied in practical operation of lots of sewage treatment works, for instance the comprehensive monitoring can be conducted on the sewage treatment process with monitoring system consisting of PLC, and moreover the acquisition of real time data distribution at several points can be conducted through filed control bus and the real time control commands can be sent out through remote computer. However such links cannot be isolated. Actually the implementation of the sewage treatment process relies on the experience of the operators to a great extent. The real data acquisition cannot timely be reflected to the process adjustment, thus the greater deviation can be avoided but the existing problems is the precision is not high and excessive reliance on the experience on the field operators.

## 2. Design on On-line Monitoring System

### 2.1. Selection and Layout of On-line Measurement Device

The on-line detecting instruments that are used in this article can be shown as follows: total nitrogen/total phosphorus/COD analyzer, Amtax™ Compact ammonia nitrogen analyzer. Sensor electrodes can be used to monitor the two parameters: ORP and PH and on-line monitor can be used to monitor the parameters such as $NO^{3-}$, $NH^{4+}$, $PO_4^{3-}$, COD, TP, TN and DO. Output signal of the instruments and electrodes is 4-20 mA direct current. There are 24 data acquisition points and output signal is analog quantity signal, which can be shown in Table 1.

**Table 1.** Statistics of sensors and executing elements.

| No. | Name | Type or specification | | Qty. |
|---|---|---|---|---|
| 1. | DO sensor | Sensor electrode | MV3030 | 2 |
| | | Transmitter | MF41 | |
| 2. | ORP sensor | Sensor electrode | MV3015 | 3 |
| | | Transmitter | EMC173-K030-F-P | |
| 3. | PH sensor | Sensor electrode | MV3010 | 1 |
| | | Transmitter | EGA173-K030-F-P | |
| 4. | $NO_3$- sensor | Sensor electrode | MV3016 | 3 |
| | | Transmitter | $NO_3$1508 | |
| 5. | $NH_4$+ sensor | Sensor electrode | MV3016 | 3 |
| | | Transmitter | $NH_4$1508 | |
| 6. | $PO_4^{3-}$ monitor | Phosphax Compact $PO_4$ | | 6 |
| 7. | TN monitor | NPW-150 | | 2 |
| 8. | TP monitor | | | 2 |
| 9. | COD monitor | | | 2 |
| 10. | Flow sensor | LWGY-40A | | 7 |
| 11. | Solenoid valve | | | 2 |
| 12. | Electromagnetic switch | | | 5 |
| 13. | Pump | BT300-1F | | 7 |
| 14. | Agitator | | | 4 |
| 15. | Air compressor | | | 1 |

The real time continuous survey and remote monitoring can be conducted on the water quality through the data acquisition on the sewage tanks so as to master the water quality situation, warn and forecast the pollution accident on the water quality and reach the emission standards. Fig. 1 is the relevant relation figures for the data acquisition points and control points. The information of the data acquisition is the water quality information obtained through the on-line measurement equipment. The main control variables include water inflow, extraction volume of clear liquid, aeration rate, internal reflux A, internal reflux B, sludge reflux and the remaining sludge displacement.

The different types of data acquired by the various water quality sensors from the different sewage tanks can be transmitted in different ways to control system consisting of IPC and PLC. Its main application is to conduct the real time monitoring the sewage treatment according to the working cycles and feedback to the system. PLC can acquire the data from the water quality sensor in a current form. In the sewage treatment process, the BCFS°,R process can play an auxiliary role in the control system, assisting the two systems in working together (distributed closed cycle control system and human-machine interactive intelligent control platform).

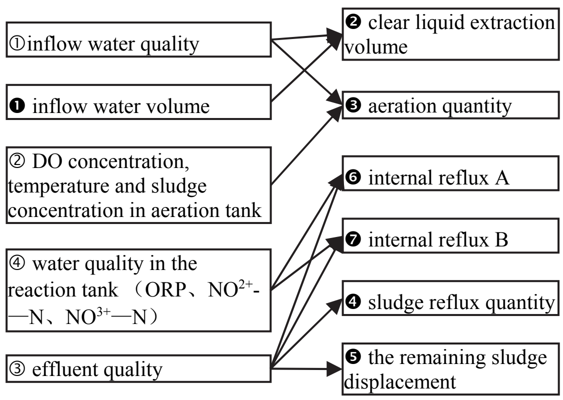


**Fig. 1.** Relation figure between data acquisition and control points.

### 2.2. Layouts of the Data Acquisition Points

Through the research on BCFS°,R process, it is preliminarily confirmed that the monitoring parameters on the inflow, effluent and each reaction tank can be shown as follows:

Water inlet R0: COD, TP, TN, $NH^{4+}$, $PO_4^{3-}$;

Anaerobic R1: $PO_4^{3-}$, ORP;

Anoxia tank R3: $NO^{3-}$, $PO_4^{3-}$, ORP;

Anoxia/aerobiotic tank R4: DO, $NO^{3-}$, ORP;

Aerobiotic tank R5: DO, $NO^{3-}$, $PO_4^{3-}$;

Flow tank (water outlet) R6: COD, TP, TN, $NH^{4+}$, $PO_4^{3-}$;

Phosphorus sedimentation tank R7: pH, $NH^{4+}$, $PO_4^{3-}$;

To clearly express the location of each water quality sensor, the layout of the main measurement instruments have been drawn out in combination with the sewage treatment process as shown in Fig. 2. The volume and types that are needed in the actual water quality monitoring in each tank can be different.

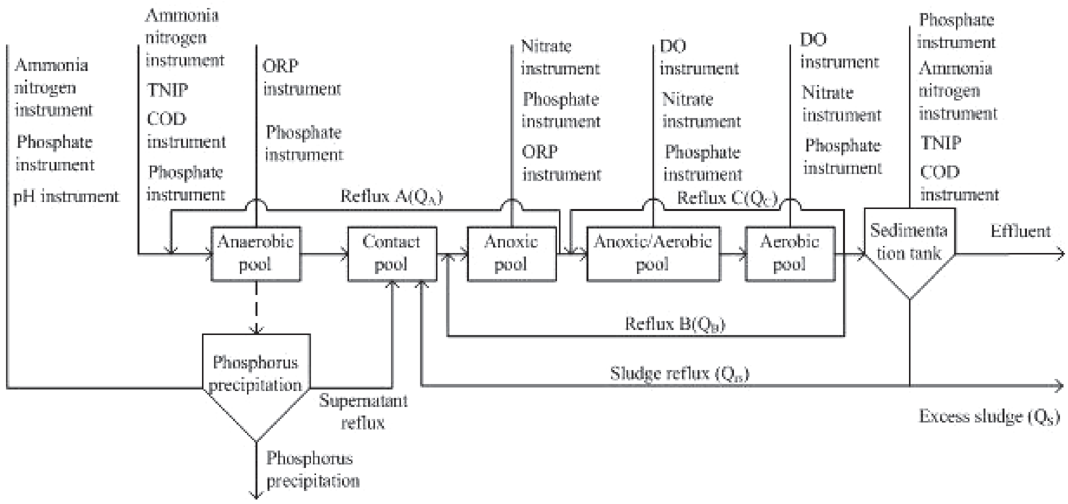


**Fig. 2.** Layout of data acquisition points.

## 2.3. Ammonia Nitrogen On-line Measuring System

In this section, ammonia nitrogen on-line measurement is taken as an example to explain the conversion relation between the direct current data acquired and concentration. Ammonia nitrogen sensors can be connected the built-in connection port. Its signal can be outputted in direct current forms (0 or 4~20 mA) with the function of port number as shown in Table 2.

The relation between ammonia nitrogen and output current can be obtained through the several measurements. Each concentration corresponds to stable current value. An approximately linear relation will be formed by connecting these points as shown in Fig. 3. Thus we can educe the relation of formula 1 and the functions of ammonia nitrogen sensor to output current has been maintained until the new concentration value has been read out.

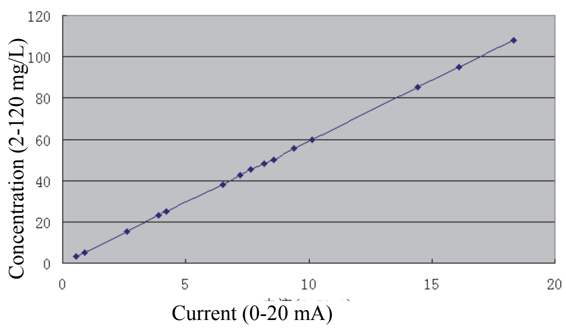


**Fig. 3.** The linear relation diagram between current acquired and concentration.

**Table 2.** Port number and functions.

| Connection port number | Design function |
|---|---|
| 1. | Wrong information –NC connection |
| 2. | Wrong information |
| 3. | Wrong information-NO connection |
| 4. | Minimum 1-NC connection |
| 5. | Minimum 1 |
| 6. | Minimum 1-NO connection |
| 7. | Maximum 1-NC connection |
| 8. | Maximum 1 |
| 9. | Maximum 1 NO connection |
| 10. | +current 1 |
| 11. | -current 2 |
| 12. | Screen current 1 |
| 13. (operational) | Minimum 2-NC connection |
| 14. (operational) | Minimum 2 |
| 15. (operational) | Minimum 2-NO connection |
| 16. (operational) | Minimum 2-NC connection |
| 17. (operational) | Maximum 2 |
| 18. (operational) | Maximum 2 NO Connection |
| 19. (operational) | +current 2 |
| 20. (operational) | -current 2 |
| 21. (operational) | Screen current |
| 22. | Not used |
| 23. | G DIN measurement bus |
| 24. | RB DIN measurement bus |
| 25. | RA DIN measurement bus |
| 26. | TB DIN measurement bus |
| 27. | TA DIN measurement bus |
| 28. | DIN shield measurement bus |

$$\frac{\text{Input current}}{\text{Concentration}} = \frac{(20-0)mA}{(120-2)mg/L} \quad (1)$$

The selected measuring range of the ammonia nitrogen sensor is 2-120 mg/L and the output signal is

0-20 mA. When the corresponding physical quantity is calculated according to the output value of the analog quantity output modules, the consideration of the input/output range and range of analog quantity output module should be taken to find out the proportional relation of the figures after A/D conversion of the measured physical quantities.

In the corresponding relations among the analog value of analog output modules and analog quantity expressed in percentage, the most important one is upper limit and lower limit (100 % and -100 %) of bipolar analog quantity range, which correspond to the analog values of 27648 and -27648. the upper and lower limits of monopolar analog quantity range (100 % and 0 %) correspond to the analog value of 27648 and 0 respectively.

## 2.4. Real Time Water Quality Parameter Display

The acquisition of other water quality parameters is similar to the data acquisition principle of ammonia nitrogen sensor. The real time water quality parameter information of each sensor corresponding to each sewage treatment tank can be obtained as shown in Fig. 4. We can also inquiry the historical information on water quality through WinCC configuration interface; moreover it can be displayed in the forms of curve and statement as shown in Fig. 5.

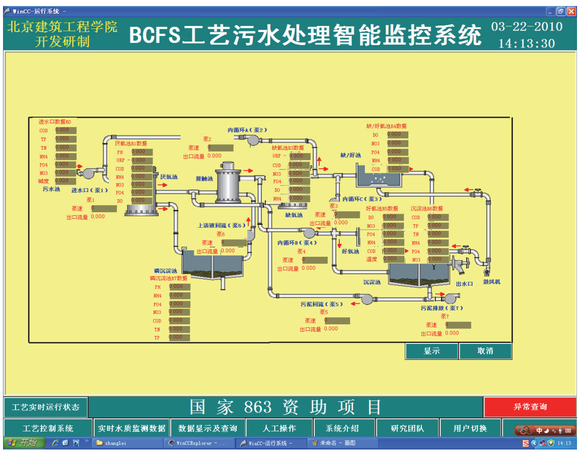


**Fig. 4.** Display of real time sewage quality parameters

# 3. Design and Realization of Expert System

## 3.1. Overall Structure of Expert System

The process adjustment implemented in the sewage treatment works is more dependent on the artificial expert, namely the experience of skilled technicians. The data information for reference is so limited. Therefore the data acquired through on-line measurement and acquisition system can meet the needs of accurate management to the sewage treatment process, thus to design the expert system with higher reliability. The structure of the expert system used in this article can be shown as Fig. 6. The data on sewage treatment is from two parts, one is the data automatically acquired from the on-line monitoring instruments, which is the main data, the other is other data temporarily inputted by the management personnel, for example, some data inputted when the deviation occurs or some data that is easily to acquire artificially but not easy to acquire by the instruments.

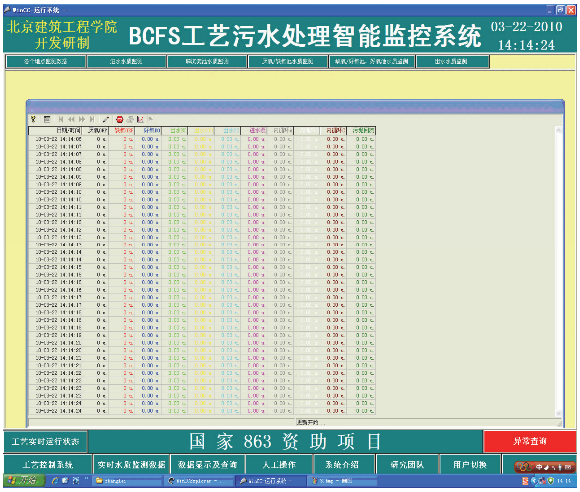


**Fig. 5.** Inquiry on historical water quality parameters.

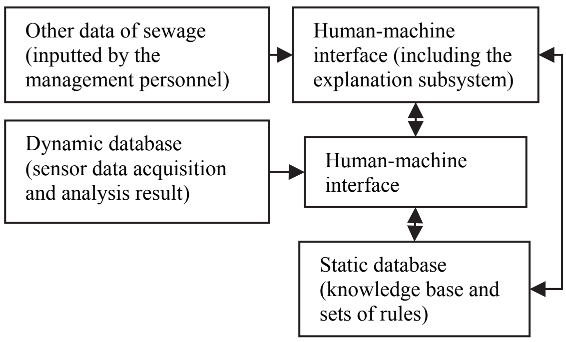


**Fig. 6.** Structure of expert system for BCFS®,R process.

## 3.2. Design on Knowledge Database

After making a comparison on the similarities and differences between database and knowledge database, this article analyzes the composition and features of the expert system related to BCFS®,R process, believing that relation database based knowledge can better manage the knowledge database with design plan given as well. Knowledge management system established with the relational data base can make the whole knowledge database have the ability to better store, maintain and extend knowledge. In this article, the rules are divided into the rule elements then the rule elements can be combined together again to from a production rule by using the relation between primary key and external key.

In BCFS°,R process, DO and ORP are taken as the main control parameters because currently the other parameters have been not allocated the real time acquisition instruments. There is some main knowledge on the controls of the aeration valves and pump in reflow process.

1. When DO is too low in aerobic tank (low than 1.5 mg/L, carry out aeration.

2. ORP is too low in Anoxic/Aerobic pool and anaerobic tank (generally above -150 mV), carry out aeration.

3. DO is too high in aerobic tank (DO in Anoxic/Aerobic pool is generally not higher than 0.5 mg/L), stop aeration.

4. The control on the cycle A, B and c of reflux pump can be conducted according to ORP reference values.

For example, to the knowledge that if the DO in the aerobic tank should generally above 1.5 mg/L, otherwise the aeration valve of Anoxic/Aerobic pool should be opened so as to improve the oxygen dissolution in the sewage, it can he expressed in the production rules as if "DO in the aerobic tank is lower than 1.5 mg/L, aeration is needed in Anoxic/Aerobic pool". The control suggestion of the system on executive components is to open the aeration valve of Anoxic/Aerobic pool. To the two water quality parameters of DO and ORP, there are 10 pieces of control rules that have been confirmed currently as shown in Table 3 through the discussion with the field operators and relevant experts.

## 3.3. Inference Engine

The composition and realization of the inference engine depend on the nature of the field related problems and expression methods and structure of the knowledge. In this project the rule based means of knowledge expression are used through the discussion with the relevant experts. As the system makes the judgment according to the data acquired, the forward reasoning driven by data is more suitable for this system. CLIPS can not only support the rule based means of knowledge expression and its reasoning mechanism is also based on forward reasoning control strategy. This can be the main reason why CLIPS language is used by the expert system in the design. CLIPS development system itself is an inference engine. In this article, the method of insertion of CLIPS into VC++6.0 is adopted so as to realize the expert system design with a good human –machine interface. The reasoning process of the expert system in the system can be shown in Fig. 7.

## 3.4. Design on Human-Machine Interface

Human-machine interface is generated under VC++6.0 development environment. Enter the system and log on the interface as Fig. 8. Input the code users' name and password and then enter expert system operation interface as Fig. 9.

**Table 3.** Control Rules about DO and ORP.

| No. | Precondition | Conclusion | Suggestions |
|---|---|---|---|
| BQ01 | DO is less than 1.5 mg/L in the aerobiotic tank R5. | Aeration is needed in the Anoxic/Aerobic pool | Open the aeration valve of Anoxic/Aerobic pool. |
| BQ02 | ORP is less than -150 mV in Anoxic/Aerobic pool R4 | Aeration is needed in the Anoxic/Aerobic pool | Open the aeration valve of Anoxic/Aerobic pool. |
| BQ03 | ORP is less than -150 mV in anoxia tank R3 | Aeration is needed in the Anoxic/Aerobic pool | Open the aeration valve of Anoxic/Aerobic pool. |
| BQ04 | DO is greater than 0.5 mg/L in Anoxic/Aerobic pool R4 | Aeration quantity is too great in Anoxic/Aerobic pool | Close the aeration valve of Anoxic/Aerobic pool. |
| HLA01 | ORP is less than -200 mV in anaerobic tank R1. | Insufficient reflux volume of cycle A | Increase the pump flow of reflux A |
| HLA02 | ORP is greater than -100 mV in anaerobic tank R1. | Too large reflux volume of cycle A | Reduce the pump flow of reflux A |
| HLB01 | ORP is less than -100 mV in anoxia tank R3. | Insufficient reflux volume of cycle B | Increase the pump flow of reflux B |
| HLB02 | ORP is greater than -100 mV in anoxia tank R3. | Too large reflux volume of cycle B | Reduce the pump flow of reflux B |
| HLC01 | ORP is less than +100 Mv in Anoxic/Aerobic pool R4. | Insufficient reflux volume of cycle C | Increase the pump flow of reflux C |
| HLC02 | ORP is greater than +300 mV in Anoxic/Aerobic pool R4. | Insufficient reflux volume of cycle C | Reduce the pump flow of reflux C |

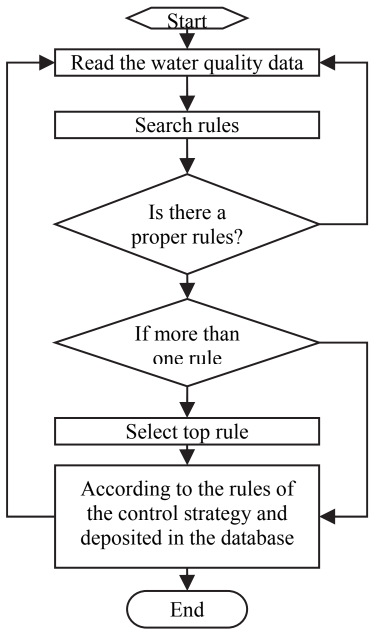


**Fig. 7.** Flow chart of inferring process of expert system.


**Fig. 8.** Interface of logging in expert system for BCFS°,R.


**Fig. 9.** Main menu of expert system.

## 4. Process Human-Machine Interface and Data Interaction of Expert System

Human-machine interface designed with Configuration software can input the data acquired into the database with data format of SQL 2000. In this system, WinCC and expert system can be located in the same computer. Direct access can be conducted to the filed database on water quality in WinCC project through ODBA or OLE-DB and then the water quality data can be read in the expert system program. The control results acquired from the expert system can be inputted into the database of human-machine interface. WinCC human –machine interface and data conversion process of expert system can be shown in the Fig. 10.

## 5. Conclusions and Prospect

With the popularization of sewage treatment process developing toward miniaturization and decentralization, some advanced sewage treatment process has been promoted to the small towns. The first and foremost problems we face in the process are the operation maintenance and daily management but there are not enough experienced technicians. This article put forward the sewage treatment process expert system based on the data automatic measurement can solve this bottle neck problem. At the first stage of the process operation, the problems such as poor data accuracy and lots of artificial intervention needed in the process adjustment. However with the data acquisition quantity increased and process operation stabilized, the system can realize the automatic operation furthest and can be directly used in the similar sewage treatment process with remarkable scaled profit.

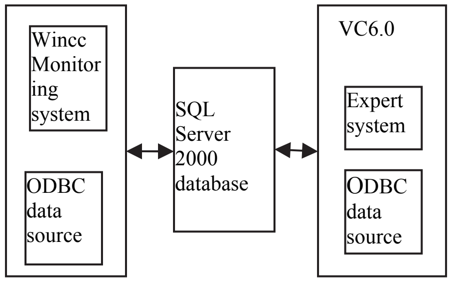


**Fig. 10.** Data exchange between WinCC and expert system.

## References

[1]. J. Baeza, D. Gabriel, et al., In-line fast OUR (oxygen uptake rate) measurements for monitoring and control of WWTP, *Water Science & Technology*, Vol. 45, Issue 4, 2002, pp. 19-28.

[2]. D. Vrecko, N. Hvala, et al., Wastewater treatment benchmark: what can be achieved with simple control?, *Instrumentation, Control and Automation*, Vol. 45, Issue 4-5, 2002, pp. 127-13.

[3]. J. Comas, I. Rodríguez-Roda, et al., Demonstration of a tool for automatic learning and re-use of knowledge in the activated sludge process, *Instrumentation, Control and Automation for Water and Wastewater Treatment and Transport Systems IX*, Vol. 53, Issue 4-5, 2006, pp. 303-311.

[4]. P. Vanrolleghem, D. Lee, On-line monitoring equipment for wastewater treatment processes: State of the art, *Automation in Water Quality Monitoring*, Vol. 47, Issue 2, 2003, pp. 1-34.

[5]. D. Choi, H. Park, A hybrid artificial neural network as a software sensor for optimal control of a wastewater treatment process, *Water Research*, Vol. 35, Issue 16, 2001, pp. 3959-3967.

[6]. K. Villez, K. Steppe, et al., Use of Unfold PCA for on-line plant stress monitoring and sensor failure detection, *Biosystems Engineering*, Vol. 103, Issue 1, 2009, pp. 23-34.

[7]. Y. Liu, P. Pei, Asymptotic analysis on autoignition and explosion limits of hydrogen–oxygen mixtures in homogeneous systems, *International Journal of Hydrogen Energy*, Vol. 31, Issue 5, 2006, pp. 639-647.