# COMPUTER SIMULATION IN HAZOP STUDIES

M J Pitt, J R Flower and M K Ben-Emhmmed
Department of Chemical Engineering, The University of Leeds, Leeds, LS2 9JT

Modern process plants are very complex and highly integrated. This complexity has made the assessment of any change difficult, if not impossible, using manual procedures. Hazard and Operability (HAZOP) Study is the most popular method used to identify hazards and operating problems in a plant under normal operational conditions or during design. Computer simulation is a helpful tool in studying a plant's behaviour during normal and abnormal conditions. This study, however, was set up to develop a procedure so that a HAZOP team can make use of computer simulation for a better understanding of a plant response to changes resulting from applying the study guide words. The possibility of including environmental protection issues as part of HAZOP concern is also demonstrated.

**Key Words:** Safety, Hazard and Operability Study, HAZOP, Hazard Identification, Computer Simulation.

## INTRODUCTION

Modern chemical and petrochemical process plants are very complex because of the trend toward large and highly integrated plants controlled by sophisticated computer systems. This complexity, however, has made the assessment of any changes difficult, if not impossible, using traditional manual methods. For safety review studies, techniques have been developed to identify hazards and operability problems for plants in normal operation or during the design process. None of these techniques provide an absolute assurance that all hazard routes and operating problems are identified and dealt with. However, when they are well carried out the risks for the plant are significantly reduced.

The most versatile technique is Hazard and Operability (HAZOP) Studies[6]. This approach provides a formal method to determine that something can go wrong but leaves ***human judgement*** to estimate the magnitude of the consequences. For small and simple facilities it is relatively easy for a group of specialists to carry out a successful safety review, but for large and complex systems where a large number of process streams, control loops, machinery, items of equipment and sophisticated computer hard and soft ware are involved, it is extremely difficult to conduct a successful study, even for people with considerable practical experience.

The interactions between the plant units, or between plants, within a large chemical or petrochemical complex make it hard to comprehend the behaviour of complete systems and eventually to judge their safety. This uncertainty is normally dealt with by adding design margins or factors of ignorance. However, a deviation at one part of a plant might lead to a dangerous situation elsewhere in the same plant, and this is also true for a plant within a complex, i.e., we might determine that every plant on its own is safe but we still have incidents and accidents.

A successful HAZOP study can only be achieved when the study team gain a comprehensive understanding of a plant's response to changes resulting from applying the study guide words. Fortunately, recent advances in computing power have made it possible to model much larger and more highly complex systems in a relatively short time and with reliable results. Computer simulation packages (both steady-state and dynamic) are available and in routine use by the majority of designers and operating companies for the purpose of control system design, evaluation of alternative flowsheets, optimisation and the investigation of plant performance.

In this study the aim was to extend the use of computer simulation in HAZOP studies. That is, to provide the study team with a tool that helps in generating a better understanding of plant response to changes in process parameters which result from applying the HAZOP guide words. This should enable the team to have a broad view on the whole system, which will lead to more justifiable actions and recommendations. A further aim is to consider both health and environmental protection issues as a part of HAZOP concern in addition to its normal safety function.

## A BRIEF DESCRIPTION OF HAZOP

HAZOP was originally introduced by ICI, and now is a widely used technique to identify hazards and operability problems in both existing plants, to improve the existing safety levels, and in plants in different stage of design (both batch and continuous). It is well known that a plant is essentially safe and operable when it operates within its design limits and that problems may arise when there is departure (deviation) from these limits. Therefore, HAZOP's main aim is to investigate how the plant may depart (deviate) from its design intention and to determine whether these deviations will produce hazards and/or operational problems. Normally, HAZOP is conducted by a multi-disciplinary team who have considerable knowledge on the process under examination. The team is led by a "team leader" who must be well trained in the technique [1,3,4,5].

In the first step, and perhaps the most important one, in carrying out HAZOP is this: the study objective should be made as explicit as possible, the plant's physical limits (boundaries) are defined and the plant documents, such as P&IDs and mechanical and operational manuals, are up-to-date, complete and representing the plant as it is (not merely as per design) or the *latest* design proposals (when the plant is still under design). After dividing the plant into manageable sections the team apply a list of guide words, which guide the discussion and stimulate creativity, to every process stream line and unit operation within the plant section. The consequences of any given deviation, the possible magnitudes of its effects, and hence its significance from a safety point of view, are decided on the basis of the team members' experience. The team reviews the existing safeguards and judge their effectiveness, and if they are found inadequate, then suggestions to reduce the likelihood or consequences of the deviation are made. These suggestions normally include changes to the operating procedure and in some cases installation of new safeguards. After all the guide words have been applied, the team moves onto another section. This systematic examination ensures that each part of the system is dealt with, "so that problems are less likely to be missed"[4].

## COMPUTER AIDS IN HAZOP

The efforts so far reported to use computers in HAZOP took two main directions. The first focused on the administrative part of the study, such as the estimation of the time needed to perform the study (Freeman, Lee and McNamara,1992), and the study recording process (Turney,1991). The second direction was devoted to the use of expert systems (Venkatasubramanian and Viadhyanathan,1994, Weatherill and Cameron,1989).

At the present time the use of computer software packages is helpful in carrying out the HAZOP study with less emphasis on clerical work; for instance: (1) In recording the proceedings of the team meeting (this allows the team leader to focus on the team discussion); (2) In the process of generating the study reports. Records of previous HAZOPs are useful in reminding the team, when examining similar plants, of the possible causes of deviations and their consequences. The use of expert systems has not been very promising, particularly those attempts to replace the HAZOP team. Thus two significant comments have been: "Attempts at converting the usual manual methods (for example the widely used HAZOP methodology) were not very successful, as significant sections of these methods are not knowledge based"[3], and "The knowledge used in a HAZOP is 'broad and deep' while expert systems are suitable only for 'narrow and deep' knowledge"[4].

HAZOP is essentially a creative methodology. Therefore, there is a danger that fixed static rules, which may not be valid in all situations, could replace or put limits to the team imagination. This imagination is fundamental to the success of the study.

## THE USE OF COMPUTER SIMULATION

As is well known, computer simulation has been around for many years and is in routine use by most of the designing and operating companies. It has been proved that computer simulation is a very helpful tool during process design and operation. Thus if this use is extended to include safety-related studies then the designers and operating companies will find themselves using tools which are already available for better design and operation. This work is an attempt to achieve this objective.

HAZOP, as the most popular hazard identification technique, was chosen to be used as the basic safety procedure to integrate safety aspects with computer simulation. It was considered that in many cases a HAZOP team would achieve sufficient understanding of the process plant response to any deviation (resulting from applying the study guide words) by comparing the plant (steady state) conditions before and after the deviation has taken place.

There are, however, other cases where the event is dynamic, for example during start-up, shutdown, or feed stock changeover. In these situations a steady-state simulator is clearly unable to report the plant behaviour during the transient. In this work two industrial case studies were used.

## *Case 1*

The Naphtha Stabiliser Unit at a petroleum refinery was simulated, using the steady-state simulator PRO/II®(Sim Sic), and subjected to HAZOP studies. The simulation outputs from the initial steady state, where the plant was operating under normal operation conditions, and a new steady state, after HAZOP guide word was applied, were kept in a database.

A FORTRAN computer program, based on the approach described in Figure 1, was developed. This can read the simulation outputs and produce the differences between the two steady states. Table 1 shows a sample of the simulation outputs when the study guide word 'More'; " More Pressure" is applied to the feed stream. If it is desirable figures for each of the two steady states can be obtained (Table 2 and 3). However, items presented in Tables 1,2 and 3 are not standard; they can be modified or even changed completely since each HAZOP study has its own characteristics, depending on the study objective(s).

As can be seen from Table 1, changes everywhere within the plant can be easily noticed. Figures 2 and 3 show the differences in graphic forms which are, in many cases, easier to understand. In these figures the temperature differences of streams entering and leaving some of the plant heat exchangers together with arbitrary safety constraints are presented. Figure 2 shows a hypothetical situation where the high and low limits are same in all streams where Figure 3 shows every stream with its own high and low limit. This clear presentation will help the team to recognise easily whether dangerous situations have developed. In the same way operational, metallurgical and environmental constraints can be used.

## *Case 2*

In case two results from a dynamic simulation of Fluid Catalytic Cracking (FCC) unit, developed by Dr X Wang, of this department were used. Figures 4,5,6 and 7 show part of the plant response when the study guide word 'Less'; "Less flow" was applied to the feed stream. If safety, metallurgical, operational and environmental constraints are fixed, this will help the team to judge the plant safety and operability during unsteady conditions.

While the use of a dynamic simulator is potentially more powerful, it is also more complex and difficult to set up. In practical terms, steady state simulation is routinely employed in design, so it can be applied immediately to the HAZOP process. Moreover, it may be observed that traditional HAZOP is effectively a consideration of steady states (e.g. design flowrate or a greater one). The guide words do not explicitly include the idea of fluctuations or rapid change. It is therefore envisaged that steady state simulation can be incorporated rapidly into HAZOP studies, but dynamic simulation may be employed in specific cases where large variation might be suspected, as shown in Figure 7.

## WHEN THE SIMULATOR CAN BE USED?

Two possibilities of using the computer simulation in HAZOP studies have been investigated.

### Outside the team meeting:

It is most probable that the simulator would be used outside the HAZOP meeting. In situations when there is no complete agreement between the team members on a particular event or when the team agree some quantitative information is required. In such situations a team member, normally a process engineer, may use the simulator and come to the next meetings "armed" with the necessary clarification and answers.

### Inside the team meeting:

A simulator could possibly also be used during the HAZOP meeting. In this case a simulator becomes virtually a "member" of the team by giving an authoritative answer to the question "what would happen if ... ?". The increasing ease of the use of simulators means it may be possible to answer some questions immediately, and if this use becomes popular manufacturers will probably be encouraged to develop a special user interface for HAZOP.

## THE ENVIRONMENTAL ISSUES

Industry is under increasing scrutiny for its effect on the environment. As a result there has recently been a substantial interest in considering health and environmental protection aspects as part of any safety review study. HAZOP, as one of the major hazards identification techniques is the principal candidate for this role.

The advantages of computer simulation would be to give precise figures on plant emissions to the atmosphere and/or liquid effluent if the process deviated in any way from design. For example, it may not be obvious how a plant running at say 90% or 110% of design (and thus perhaps hotter or cooler) affects the minor components of its outflows. Material balance checks (of simulator output against the real plant figures) would help the team to check if there is any leakage into the environment, for example of toxic liquid into the cooling water system from one of the heat exchangers or gases released to the atmosphere through a heater or a boiler.

The HAZOP team may use available environmental protection control standards, such as the allowable levels of phenols to be sent to the river or to the sea, as a constraint (Fig. 5 gives an example) so operation procedures or design proposals can be modified accordingly.

## CONCLUSION

As process plants grow larger and more complex, so the effects of any change become more complex and difficult to assess using traditional manual methodologies. In this work we have demonstrated a robust and reliable strategy of using computer simulation in HAZOP. Rather than requiring extra expenditure, this is a way of getting further returns from the money that has been spent to buy or to rent the simulator. Simulators, as a supporting tool, will provide information on plant deviation which would be helpful to a HAZOP team to understand plant response to any changes resulting from applying the study guide words.

There would be tremendous improvement in the study findings which will be more accurate and justifiable since now these are based on real figures rather than hypothetical ones assigned by the team members based on supposition and/or experience. Moreover, the contribution by experts, who often are not available to contribute fully to the study, would be required less, because a simulator will fill a considerable part (though not all) of the gap their absence may produce. Moreover, as the team will be more confident of their understanding, the overall time may be less.

It is anticipated that in the future computer simulation files will be submitted to the owner as part of the plant documents such as CAD files and mechanical and operational manuals. This will eliminate the need to build a computer model just for HAZOP.

Finally, the health and environmental issues can now be better evaluated as a part of HAZOP since the team are able to learn how much hazardous materials are released to the atmosphere and/or to the ground when there are abnormal process conditions.

## Acknowledgements

The authors would like to thank Dr X Wang , Department of Chemical Engineering - University of Leeds, for his kind permission to use some results of the FCC dynamic simulator.

## REFERENCES

1. **Chemical Industries Association,** 1977, *A Guide to Hazard and Operability Studies*, ED.1
2. **Freeman, R. A., Lee, R.** AND **McNamara, T. P.,**1992, *CHEM. ENG. PROGRESS*, AUGUST, 28
3. **Goring, M. H.** AND**Schecker,H.G.,**1992, *EUROP.SYMP.ON COMP.AIDED PROC.ENG.-2*, S429
4. **Kletz , T.,** 1992 "*HAZOP and HAZAN*", *INSTITUTION OF CHEMICAL ENGINEERING*, ED.3
5. **Lawley H G**, 1976, *HYDROCARBON PROCESSING*, April, 247
6. **Ozog Henry** and **Bendixen Lisa**, 1987, *CHEMICAL ENGINEERING PROGRESS*, April, 55
7. **Turney, R. D.,** 1991, *ICHEME SYMPOSIUM SERIES NO. 124*, 299
8. **Venkatasubramanian, V.** AND **Vaidhyanathan, R.,** 1994, *AICHE JOURNAL*, 40, 3, 496
9. **Weatherill, T.** AND **Cameron, I. T.,** 1989, *COMPUTERS AND CHEMICAL ENGNG.*,13,(11/12),1229

***TABLE 1.0*** ***The difference between Base Case and Study Case***

| Stream Number | | 9 | 10 | 11 |
|---|---|---|---|---|
| Stream Name | | P1 OUT | E2 OUT | V4 FEED |
| Liquid Flow | $m^3h^{-1}$ | 0.003 | 0.053 | -8.440 |
| Vapour Flow | $m^3h^{-1}$ | 0.000 | 0.000 | 0.177 |
| Operating Temperature | K | -0.154 | 0.000 | 0.000 |
| Operating Pressure | k Pa | -113.071 | -113.071 | -113.071 |
| Mole Fraction Liquid | | 0.000 | 0.000 | -0.086 |
| Density | kg $m^{-3}$ | -0.020 | -0.324 | N/A |
| Specific Heat | kJ $kg^{-1}$ $K^{-1}$ | -0.021 | 0.156 | N/A |
| Enthalpy | kJ $kg^{-1}$ | -4116.562 | -435.000 | 151012.750 |
| Average Molecular Weight | | 0.000 | 0.000 | 0.000 |

***TABLE 2.0*** ***Base Case : Plant under normal operation conditions***

| Stream Number | | 9 | 10 | 11 |
|---|---|---|---|---|
| Stream Name | | P1 OUT | E2 OUT | V4 FEED |
| Liquid Flow | $m^3h^{-1}$ | 84.786 | 95.084 | 93.021 |
| Vapour Flow | $m^3h^{-1}$ | 0.000 | 0.000 | 0.270 |
| Operating Temperature | K | 306.836 | 378.150 | 428.150 |
| Operating Pressure | k Pa | 1130.710 | 1032.643 | 934.576 |
| Mole Fraction Liquid | | 1.000 | 1.000 | 0.860 |
| Density | kg $m^{-3}$ | 653.417 | 251.635 | N/A |
| Specific Heat | kJ $kg^{-1}$ $K^{-1}$ | 216.167 | 0.000 | N/A |
| Enthalpy | kJ $kg^{-1}$ | 230758.734 | 1769513.250 | 3245130.750 |
| Average Molecular Weight | | 92.532 | 92.532 | 92.532 |

***TABLE 3.0*** ***Study Case: The guide word "More" "More pressure" was applied***

| Stream Number | | 9 | 10 | 11 |
|---|---|---|---|---|
| Stream Name | | P1 OUT | E2 OUT | V4 FEED |
| Liquid Flow | $m^3h^{-1}$ | 84.784 | 95.031 | 101.461 |
| Vapour Flow | $m^3h^{-1}$ | 0.000 | 0.000 | 0.093 |
| Operating Temperature | K | 306.991 | 378.150 | 428.150 |
| Operating Pressure | k Pa | 1243.781 | 1145.714 | 1047.647 |
| Mole Fraction Liquid | | 1.000 | 1.000 | 0.946 |
| Density | kg $m^{-3}$ | 653.437 | 582.979 | N/A |
| Specific Heat | kJ $kg^{-1}$ $K^{-1}$ | 216.188 | 251.479 | N/A |
| Enthalpy | kJ $kg^{-1}$ | 234875.297 | 1769948.250 | 3094118.000 |
| Average Molecular Weight | | 92.532 | 92.532 | 92.532 |

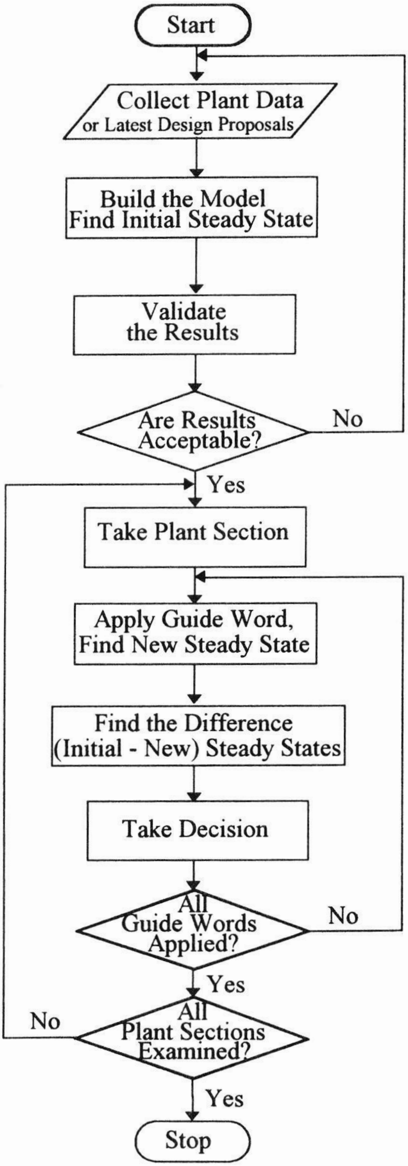
Start
Collect Plant Data or Latest Design Proposals
Build the Model Find Initial Steady State
Validate the Results
Are Results Acceptable?
No
Yes
Take Plant Section
Apply Guide Word, Find New Steady State
Find the Difference (Initial - New) Steady States
Take Decision
All Guide Words Applied?
No
Yes
All Plant Sections Examined?
No
Yes
Stop

Figure 1

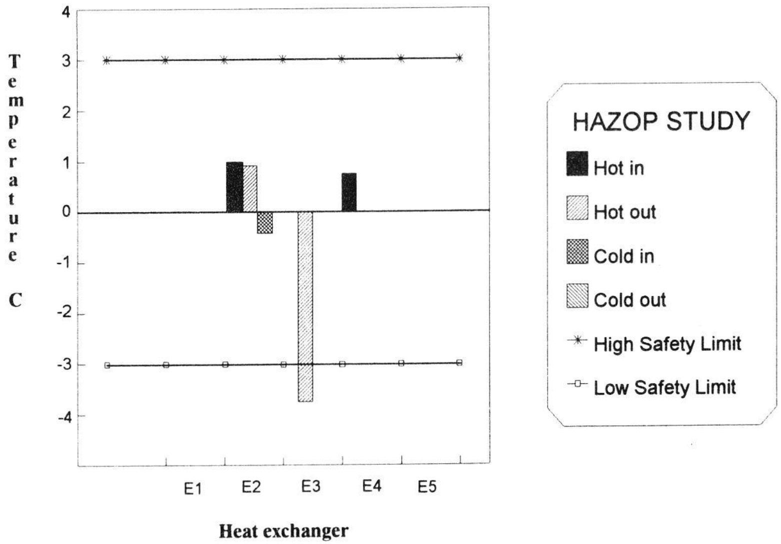

Figure 2 All streams with same high and low temperature limits

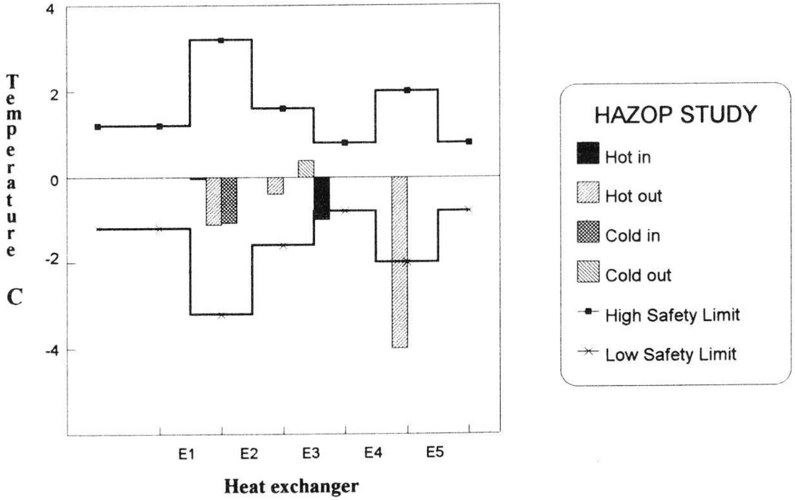

Figure 3 Each stream with its own high and low temperature limits

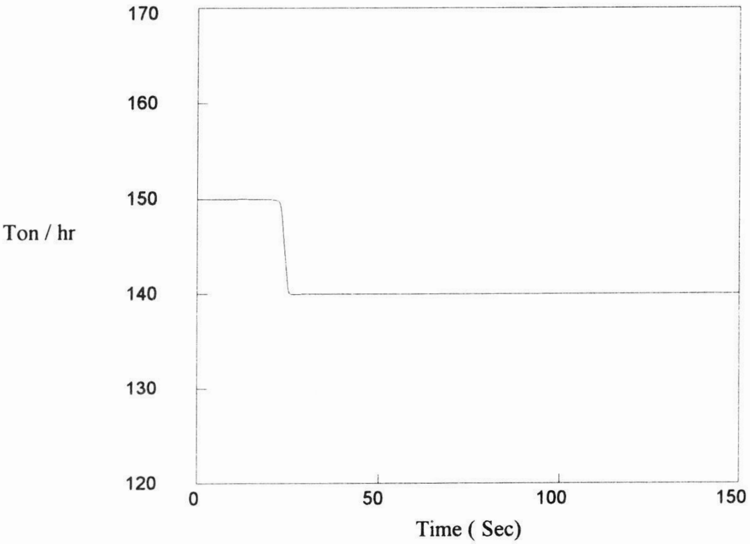

Figure 4 FCC Feedrate change

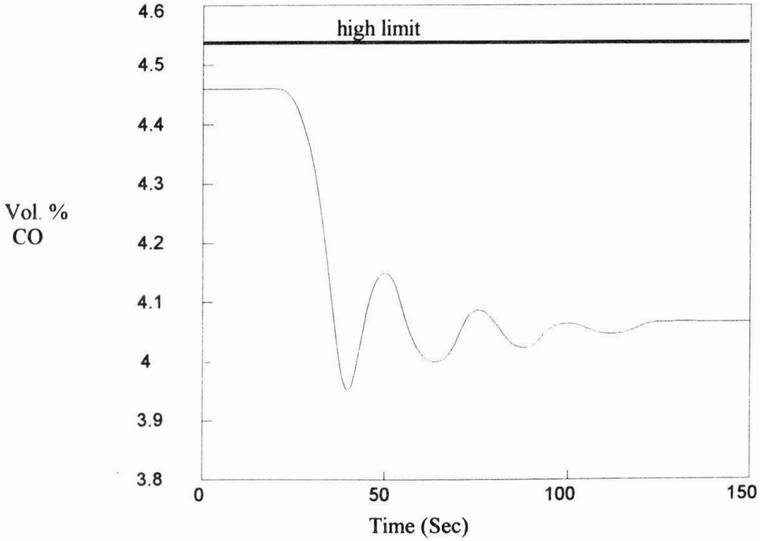

Figure 5 Volume % CO in the flue gas

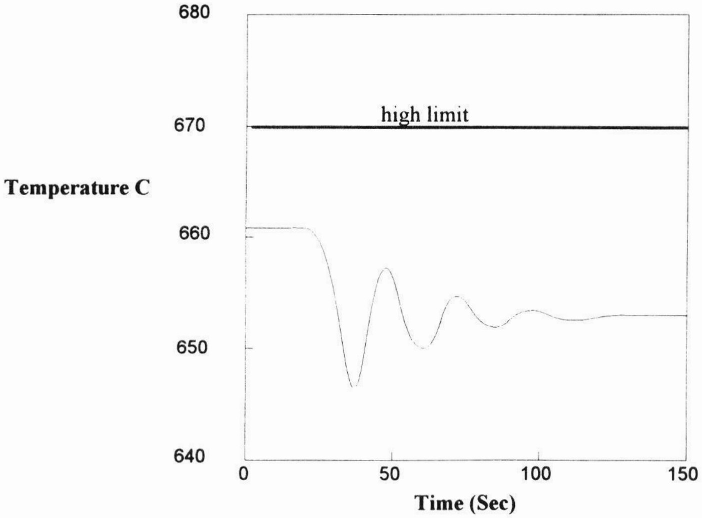

**Figure 6** Regenerator temperature response to feedrate change

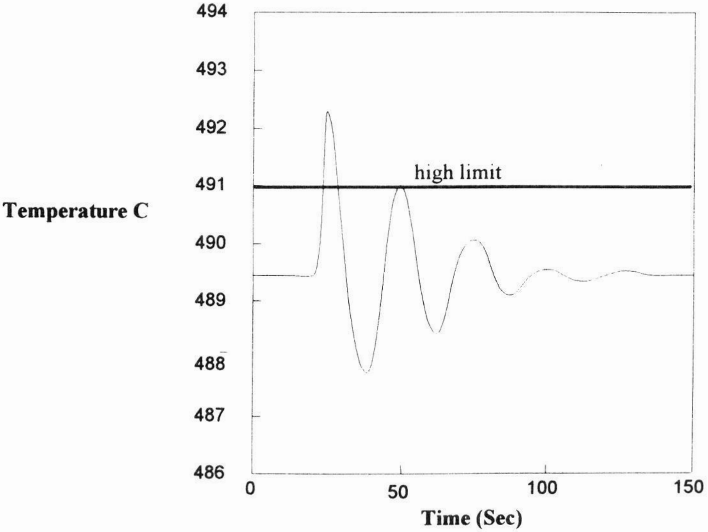

**Figure 7** Reactor temperature response to feedrate change.