Detecting Points Needing Temperature Control in a Heat Exchanger Network using a Commercial Simulator

Helvécio Guimarães, Roger Zemp
Department of Chemical Systems Engineering
Campinas State University
C.P. 6066 – CEP 13083-970
Campinas – S.P. – Brazil

Abstract *– It's presented here a new tool in learning some basic aspects of Chemical Engineering: an industrial process simulation. Taking some data from literature, we considered a heat exchange network in a simulator. With some variations in a stream property, it's possible to detect a propagation of a disturbance. So, the students can detect points in the net needing some kind of control, besides learnig which variation cause a specific disturbance.*

Introduction

Instituted since the beginning of the 2o. semester of 1996, the project REENGE-FEQ has been presenting very estimulating results. In this 2nd semester of 1997, the team counted on 7 students of graduation of their institut. Our objective was the complete implementation of the computer in the students' academic life; not simply as a sophisticated typewriter, but as learning tool.

With that objective in mind, several works were proposed. Our tools were AutoCAD for drawing of unitary operations (filters, mixers, heat exchangers); MatLab, for control algorithms implementation; and HYSIM, an industrial process simulator. All the works were accomplished seeking to presenting the students new resources that complement its academic formation.

It is presented here a study of disturbances´ propagation in a heat exchanger network. The study is presented as form of detecting points in need of temperature or flow control of a certain stream.

Simulation´s Introduction

The process in an industrial plant is divided in several stages. In each one of those stages a certain phenomenon is foccussed and will be treated along the process. The raw material, that begins the process, is being transformed in a desirable product.

All the stages of an industrial process are interlinked. Any alteration in variables of a certain operation (a stream´s temperature or flow, i. e.) may bring drastic changes in the process, since it will affect a series of subsequent operations. To avoid problems or even a failure in the process, control instruments are used, aiming to correct small mistakes that may happen during the process. If the instrument detects some variation out of the expected range, it starts to carry out a set of instructions to restaure the process around the desired conditions. In some cases, an alarm is switched on to avoid failure of the plant or risk conditions for either the operators or enviroment.

The objective here is to study the control instruments installation in a heat exchanger network. As will be presented later, a disturbance in a stream causes variations along the net that can be serious in an industrial plant. For the accomplishment of the study, the commercial simulator HYSIM^{TM} was used. The net was simulated using data obtained from the literature.

Basic Concepts

The heat exchanger is a heat transmission equipment that recovers heat from process streams. There are some specific types: monotubular, mutlitubular, shell and tube, etc. In this contribution, the shell and tube heat exchangers available in the simulator will be considered.

The operation of a shell and tube heat exchanger is relatively simple: a stream flows in tubes inside of a shell, other stream flows in the shell, among the tubes and promoting heat exchange. Figure 1 shows a heat exchanger and 4 streams.

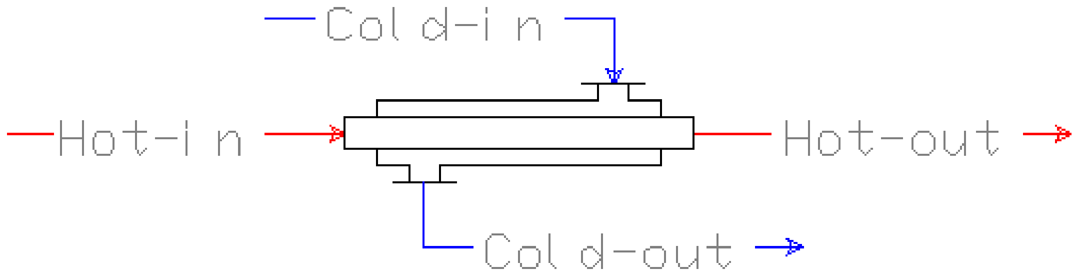

Figure 1. Heat Exchanger Schematics

Since the heat exchange between the streams depends on the properties of each stream, as flow and temperature, any alteration in the inlet streams´ properties causes alterations in the outlet streams´. In the illustration above, when Hot-in´s temperature goes down, Hot-out´s temperature also drops, as well as Cold-out´s temperature. Similar effects would be gotten with different perturbations in inlet streams.

When working with a heat exchanger network, the problem is more complicated. Change in one of the properties of any inlet stream may bring a propagation of variations, since the heat exchangers are interlinked. If previously 2 streams were affected, now the effect can be much more devastating, since the outlet stream of a heat exchanger entering another one produces a new sequence of alterations. Next illustration shows the net studied in the present project.

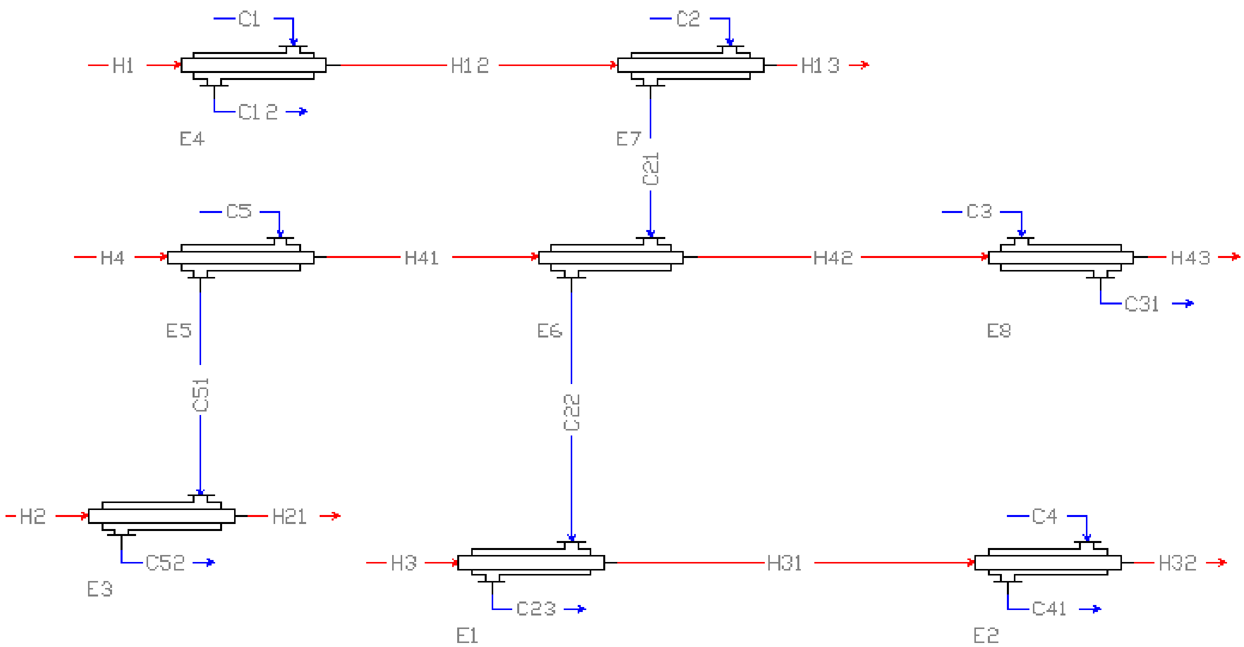

Figure 2. Heat Exchanger Network

The heat exchanger are nominated using the code *Ex*, with x being from 1 to 8. The hot streams have initial H, while the cold ones have initial C. If the stream H1, i. e., suffers a temperature alteration, will also be disturbed streams C12, H12, H13, C21, C22, C23, H42, H43, C31, H31, H32, C41. Thus it´s needed to study the behavior of the net due to such disturbances, seeking to the installation of instruments that will allow the control of a stream´s flow or temperature.

Project Data

The data of the project were obtained from the work [1], as well as the heat exchanger network illustrated in figure 2. Enclosed, there are available stream´s data (temperature, pressure drop´s, flows, etc) that were used in the simulation. As the work just referred to an aromatic plant, and nothing was specified concerning the composition of the streams, benzene was used as the hot streams and toluene as the cold streams.

Heat exchanger data were also supplied. In this stage of the project, it was simulated simple heat exchangers, not using any of the supplied physical properties.

With the data available, it was possible to start the simulation. Most of the supplied data were not useful, since Hysim couldn´t use all of them. Streams´ flows, pressure drops in heat exchangers, inlet temperatures and heat transfer global coefficients were used.

The Simulation

Simulator HYSIM, when treating a heat exchanger network takes into account 3 equations to make the energy balance in each heat exchanger, to know:

$$Q = U * A * \Delta T \text{ (I)}$$

$$Q = m_1 * Cp_1 * \Delta T_1 \text{ (II)}$$

$$Q = m_2 * Cp_2 * \Delta T_2 \text{ (III)}$$

The equation I represents the energy balance in the heat exchanger, while the equations II and III refer to the balance of the inlet streams. In this simulation, the net has 8 heat exchangers, what leads to 24 equations to be solved. Since the system is not linear, under certain conditions the software doesn't get numerical convergence for the energy balance in a certain heat exchanger. It is a serious problem, because if a balance is not satisfied in any of the heat exchanger it can stop the whole simulation. This have lead to a severe problem in adjusting the simulation to an initial steady state.

Another problem found during the simulation was benzene´s and toluene´s phase change. The proposed system works with high temperatures, which may go ahead of ebullition point, under constant pressure, of some of the streams. Considering the analysis effects proposed here, that phase change is harmful, since it alters the outlet temperature of some streams. If a cold stream receives enough heat to vaporize it partially, its outlet temperature can be smaller than its inlet, since part of exchanged heat was consumed during phase change. To solve that problem, streams´ pressures were specified intending to avoid phase change. Among the simulation data can be found pressures up to 20 MPa, which is quite high.

Study of Disturbances Propagation

Having been determined the initial state for simulation, the propagation of the disturbances was considered. This study seeks to improve undergraduate students to improve their skills to develop simulation type of the work which ids very requested area besides being very estimulating. This study allows the identification of which streams are more strongly linked to the net, and mainly which one´s behaviors influence the network global behavior.

To study the propagation, was imposed positive and negative variations, around 10% of the nominal values, in flows and temperatures of the main streams linked to the process: H1, H2, H3, H4, C1, C2, C3, C4, C5. The variations were imposed separately, to facilitate understanding of the network behavior. To each variation, the simulator recalculates energy balances of heat exchangers affected with the changes in the process, and supplies new temperatures of the streams affected with such variation. It was possible, in this way, to detect which streams are more strongly influenced in the process.

Data of Disturbance

Here, there are some tables illustrating the effect of the propagation of disturbance. Some data are totally inexpressive, while others are still quite significant.

Table 1. Streams´ temperature variation under influence of H1´s temperature

ΔT H1	+10%	-10%
ΔT H12	-1,5%	-2,75%
ΔT H13	+0,8%	+1,6%
ΔT C21	-0,3%	-0,6%
ΔT C22	-0,06%	-0,1%
ΔT C23	-0,03%	-0,08%
ΔT H42	-0,1%	-0,2%
ΔT H43	-0,04%	-0,08%
ΔT C31	-0,1%	-0,2%
ΔT H31	-0,01%	-0,03%
ΔT H32	≈0	≈0
ΔT C41	-0,01%	-0,02%

An analysis of the data presented above leads to the following conclusion: in spite of influencing the temperature of several streams of the process, stream H1´s temperature doesn't deserve special attention with its control, being considered that variations up to 10% are accepted. The largest consequent variations happened with stream H12, which is derived directly from H1. The largest observed variation was 2.75%; other streams have presented significantless variations in their temperature, ranging from no variation to +1.6%, case of the stream H32.

Table 2. Streams´ temperature variation influenced by H1´s flow

ΔQ H1	+10%	-10%
ΔT H12	+4,9%	-6,0%
ΔT H13	+7,4%	-6,5%
ΔT C21	+4,7%	-5,0%
ΔT C22	+0,9%	-0,9%
ΔT C23	+0,6%	-0,6%
ΔT H42	+1,3%	-1,4%
ΔT H43	+0,5%	-0,6%
ΔT C31	+1,3%	-1,4%
ΔT H31	+0,2%	-0,2%
ΔT H32	+0,03%	-0,03%
ΔT C41	+0,2%	-0,2%

The previous data are about H1´s flow influence on the temperatures of all streams tied up to her. As can be seen, H1´s flow control is only significant when variations of final outlet temperatures of the stream H13, because although influencing significantly C21´s temperature (approximately 5%), it doesn't bring important modifications in behavior of other streams that were affected with variation of temperature from +1,3% to -1,4%, and 5 of them had inferior alteration at 1%.

Table 3. Streams´ temperature variation influenced by C4´s temperature

ΔT C4	+10%	-10%
ΔT C41	+1,56%	-1,55%
ΔT H32	+9,0%	-9,0%

In the case above, although influencing just 2 streams, C4´s temperature should be under certain control. Stream C4 influences the stream C41, that derives directly from C4, but brings great variations to the outlet temperature of the stream H3, represented by the temperature of H32. If, i. e., the stream H32 has to enter another part of the process, this variation cannot be desirable.

If the mentioned data were analyzed in another way, the objective to the simulation changes a little. Be supposed that, for permanent alterations in the process, C4´s temperature suffers an increment of the order of 10%; intending to maintain temperature of stream H32, that will enter another stage of the process, it should be determined, which increase has to be done in heat exchanger E2´s area. Being known that the area of the heat exchanger is 607,1 m^2, its area should be increased in 2,4 times.

Table 4. Streams´ temperature variation influenced by C4´s flow

ΔQ C4	**+10%**	**-10%**
ΔT C41	-4,3%	+5,0%
ΔT H32	-1,5%	+2,2%

It is noticed above, unlike the table 3, that C4´s flow control can just be significant when expressive variations in C4´s outlet temperature, which can arrive approximately 5%, are not wanted. If attentions were, previously, over H32, now they are over C41, with the same analysis: if C41 reenters the process and its temperature cannot present certain variations, controllers should be settled to C4´s flow.

An interesting and significant situation is represented by the stream H2. Let´s take a look in the table above:

Table 5. Streams´ temperature variation influenced H2´s temperature

ΔT H2	**+10%**	**-10%**
ΔT H21	+2,3%	-2,2%
ΔT C52	+8,8%	-8,8%

In this case, as can be noted, H2´s temperatures demands control, since great deviances (8.8%) were found in C52´s temperature. It can be taken here the same procedure used in C4 analysis.

Being considered now H2´s flow, the problem becomes different, as shown below.

Table 6. Stream´s temperature variation influenced H2´s flow

ΔQ H2	**+10%**	**-10%**
ΔT H21	+2,3%	-2,2%
ΔT C52	+1,1%	-1,5%

In this case, H_2´s flow no longer requests the employment of a control instrument, since the caused variations are not very expressive.

Observations

Besides the data presented above, were presented other similar series, not presented in this work, since they are quite similar to the data presented here. It should be stood out that the simulation has a limited analysis if process and operation conditions aren´t known. As already mentioned, streams´ fluids were arbitrated. On the other hand, this analysis cannot be significant in a certain process that, i. e., accept variations up to 20% in streams´ temperature. The qualitative analysis becomes, in this case, much more expressive.

The simulator doesn't allow to obtain data under certain simulation conditions, difficulting obtaintion of certain information. For example, in this simulation was not possible to study the effect of the fall of 10% in the C5´s temperature, because the simulator doesn't get the convergence for the energy balance in heat exchanger E5.

Conclusion

The objectives of the first part of the project were achieved. New forms of studying and learning are being presented in the Chemical Engineering Course, at Unicamp. Information of students´ interest in the Internet, ready simulations to be studied; with those activities, the teaching of the engineering in this college starts to assume new forms. It is technology employment in teaching.

In the simulation, the main streams were analyzed as a study of control equipment installation. This analysis is expected to be done by the undergraduate students. With this steady-state simulation, students come closer to reality and start playing an educational question-answer game with the network simulation, which will be very useful for their understanding in chemical engineering basic concepts.

Unhappily, even so, the simulator limits certain conditions generating difficulties in settling down a certain operational state. That limitation was the main problem found in the accomplishment of this work.

References

[1] Polley, G.; Shahi, M., "Interfacing Heat Exchanger Network Synthesis and Detailed Heat Exchanger Design", *Chemical Engineering Research and Design*, Vol 69, No. A6, November 1991, page 445.

[2] Kern D., "Processos de Transmissão de Calor", 1980, Ed. Guanabara Dois, Rio de Janeiro - RJ.