STABILITY CONDITIONS OF A PLATE HEAT EXCHANGER+

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Abstract

The stability condition of the plate heat exchanger (PHE) which is dynamically highly nonlinear can be limited by using the experimental phase plane technique. This technique proved to be better and more accurate compared with other methods which are needed to solve a set of theoretical complex differential equations to study the stability of PHE. The accuracy of this technique can be increased by increasing the numbers of on-line detectors which are implemented with digital computer.

المستخلص

ان ظروف الاستقرارية لمبادل حراري صفائحي (ديناميكيا لاخطي) يمكن تحديدها باستخدام اسلوب رسم خارطة الطور العملي للمتغيرات . ان هذا الاسلوب هو الأفضل والأدق (كونه يعتمد على نتائج عملية) مقارنة بالطرق الاخرى التي تحتاج الى حل معادلات تفاضلية نظرية معقدة . يمكن زيادة الدقة لهذا الاسلوب وذلك بزيادة عدد المتحسسات لمتغيرات العملية وربطها مباشرة بحاسبة رقمية .

Nomenclature

F_1 : Cold water flow rate (Kg / sec).
F_2 : Hot water flow rate (Kg / sec).
kc : Proportional gain (-).
T_1 : Inlet temperature of cold water (°C).
T_2 : Outlet temperature (controlled variable) of cold water (°C).
T_3 : Inlet temperature of hot water (°C).
T_4 : Outlet temperature of hot water (°C).
T_I : Integral control time constant (minute).
T_D : Derivative control time constant (minute).
t : Time (minute).

Introduction

The heat exchanger is usually considered to be an accessory piece of equipment in the modern chemical plant. This type of exchanger is usually used in food and drug industries as well as in the refrigeration plants due to the ease of cleaning and inspecting of surface [1].

A plate exchanger consists of a frame and corrugated or embossed metal plates. The corrugation imparts turbulence to cold and hot streams flow in alternate spaces between the plates.

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The heat exchanger parameters are distributed and highly interacted, the exact dynamics for a nonlinear counter current exchanger are quite complex, consequently a digital computer will have to be used to determine the response of the system [2].

The dynamic characteristics regarding shell and tube and double pipe heat exchanger are now well established while the existing dynamic characteristics on plate heat exchangers are rather limited and confined mainly to the patent literature.

The analysis of the stability for the nonlinear PHE is usually the most important to design and select the suitable automatic control system.

Stability Analysis

A stable system will be defined as one for which the output response is bounded for all bounded input. A system exhibiting an unbounded response to abounded input is unstable.

The analysis of the stability for anon-linear system can be carried out by three general methods [3] which are :

1. **Local linearization method** : it is called the first Liapunov method which depends upon the linearization of the differential equations of the system around the steady state point, and then establishing the characteristic equation from process state matrix.
2. **The second method of Liapunov :** it is also called the direct method of Liapunov which is applied to systems of any order. By this method the stability of the system can be determined without solving the state equations.
3. **Phase plane technique :** this technique introduced by Pioncare is a method for obtaining graphically the solution of high order differential equations. It is especially useful for dealing with systems with gross non-linearities. Different from the describing-function method, the phase-plane technique is not restricted to small nonlinearities. The path or the motion of the process variables with respect to another can be represented by curves or trajectories, then the family of these is called a phase-plane portrait.

Construction of the Trajectories

Since the simulated differential equations of the present PHE were complex and highly nonlinear. the analytical methods are not useful here because the time solution of the system differential equations could not be easily obtained.

The experimental technique is used in the present work to obtain the process variables-trajectories of the phase plane. The accuracy of this technique is higher, since it depends upon the actual experimental data which is obtained by advanced instruments such as; sensors, X-Y recorder and on-line digital computer.

For most heating systems, the critical variables is the temperature inside the system, then the trajectory of this variable is more effective and sufficient to get clear picture For limiting the stability of the system [4].

In the present work, since the critical variable which is responsible for the stability of the PHE is the temperature., the experimental phase planes are plotted as the rate in change of temperature (dw / dt) against temperature (T_2).

Experimental work

The central piece of set-up in the present work is the PHE, model : α – Laval , Po1 , containing 21 stainless steel plates, with herring-bone pattern, assembled in counter current configuration, single-pass / single-pass, each 10 channels per pass. The maximum working temperature and pressure are 130 °C and 16 bar respectively. Water is employed due to its high heat capacity making it almost the universal cooling medium. The multichannel digital recorder which is used with multipoint temperature indicator type-TR-2721, is manufactured by "Tekeda Riken Industry Co., Ltd", with resolution of 0.1 °C. The three term PID controller, "Honeywell", type-7450, with accuracy of 99% of full span (0-100 °C) is used to control the system. The operating conditions of the system are shown in Table (1), while fig (1) shows the input / output variables of the PHE.

Table (1) : Range and Scope of experimental

<table>
<tr><th>CONDITION</th><th colspan="2">STEADY STATE FLOW RATE KG / SEC.</th><th colspan="2">INITIAL STEADY STATE TEMPERATURE, °C</th><th rowspan="2">DESIRED TEMPERATURE, T_2 ,°C</th><th rowspan="2">- VE STEP CHANGE OF WATER STREAM RATE</th></tr>
<tr><td rowspan="2">Transient state (Step disturbance)</td><td>Cold stream F_1</td><td>Hot stream F_2</td><td>Cold stream T_2</td><td>Hot stream T_3</td></tr>
<tr><td>0.167</td><td>0.275</td><td>30</td><td>40</td><td>34</td><td>20 %
50 %</td></tr>
</table>

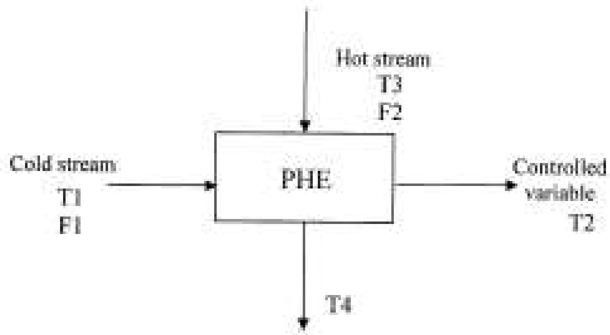


Figure (1) : Block diagram of input / out put variables

<u>Results and Discussion</u>

From the dynamic analysis of the PHE, the steady state gains (sensitivity) of controlled variables (T_2) to cold water from rate (F_1) and hot water flow rate (F_2) an:

$$\frac{T_2}{F_1} = -30.03 \quad C^o / Kg / \sec \qquad \ldots (1)$$

$$\frac{T_2}{F_2} = 12.8 \quad C^o / Kg / \sec \qquad \ldots (2)$$

From above, one could conclude that (T_2) is more affected by F_1 than F_2.

Open Loop Analysis

The phase plane (process path) for (step changes disturbances) in the open loop heat exchanger is explained in Fig (2). From the profile of experimental phase, one can say that the equilibrium point (34 °C) is unstable node type. The instability of the PHE is due to insufficient heat transfer between the cold and hot side streams during transient state of the process.

The dynamic performance of the heat exchanger is influenced by the efficiency of its heat transfer. Relative capacity of demand to supply is important in the dynamics of PHE performance. If the demand of the process was larger than the supply side heat capacity, the control problem was less critical than if the opposite was true, this affectes directly the stability of the PHE.

However, it is recommended to use closed loop (controlled) system with PID algorithm to operate the PHE at the stable conditions [5,6].

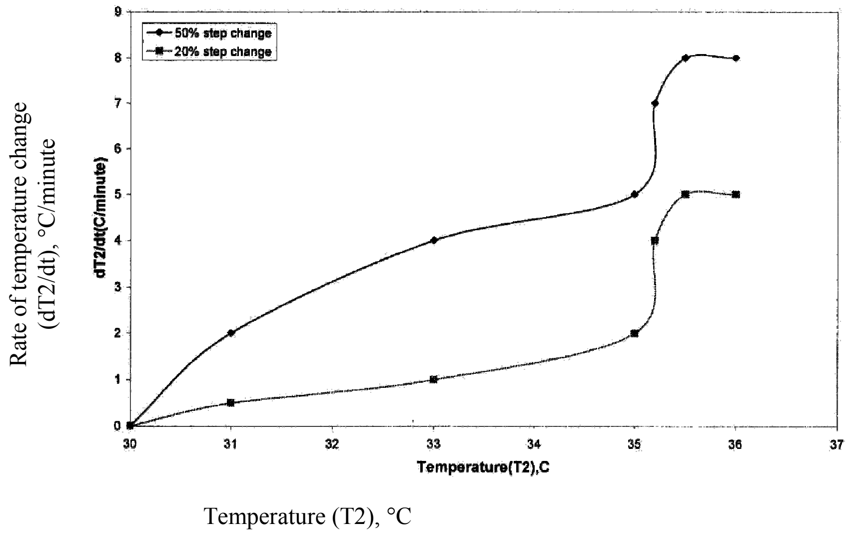


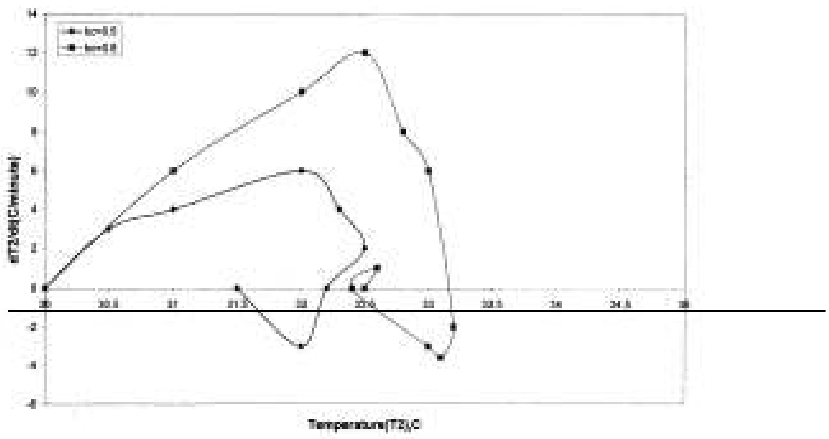
Figure (2): The phase-plane of the open loop system against 20% and 50% (-ve step change) in F_1

Closed Loop with P-control

Fig (3) illustrates the phase plane for various values of proportional gains (kc) against 20 % (–ve step change) in cold water stream F_1 (regulating mechanism). For kc of 0.5, the process path (trajectory) had stable conditions (node type) around the new steady state (31.5 °C). When the kc increases to 0.8, the system has more oscillation and the trajectory path seems as a stable node and finally tends to have a spiral form around new steady state point (32.5°C).

The offset (steady state error) regarding equilibrium point (34 °C) could be decreased by increasing the value kc as a result of increasing the speed of response. The limit cycle dose not appear in the present work as a result of hunting oscillation (at maximum value of kc which is undesirable condition), at which the control system exhibits marginal stability.

Rate of temperature change (dT2/dt), °C/minute



Temperature (T2), °C

Figure (3): The Process path of the PHE for P-control

<u>Closed Loop with PI and PID Control</u>

Fig (4 & 5) shows the phase plane of PI and PID control of PHE under the same conditions were used with P-control. The trajectories of PI has the spiral motion (stable focus) around that the steady state point (34 °C). The system becomes oscillatory due to the integral mode which tend to form focus path. The oscillatory and offset are eliminated at the final steady state (thermally equilibrium) and then the process becomes stable. For a fixed value of kc (0.5), the decreasing of the integral time (TI) from 0.3 to 0.1 minute decreases the maximum deviation and period which made the response more oscillatory (fig 4).

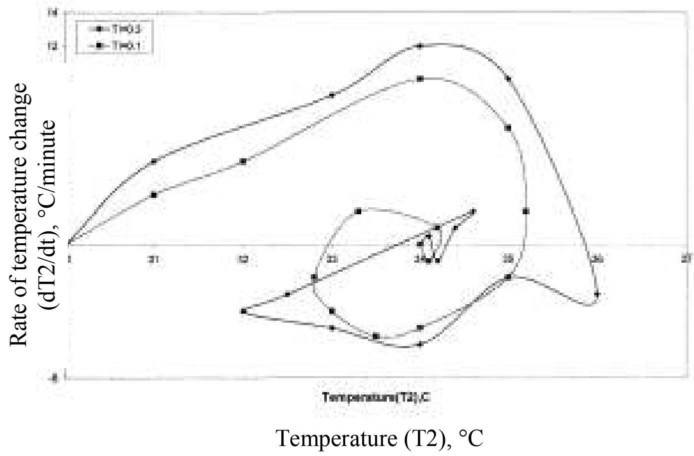


Figure (4): The phase-plane of the system for PI control

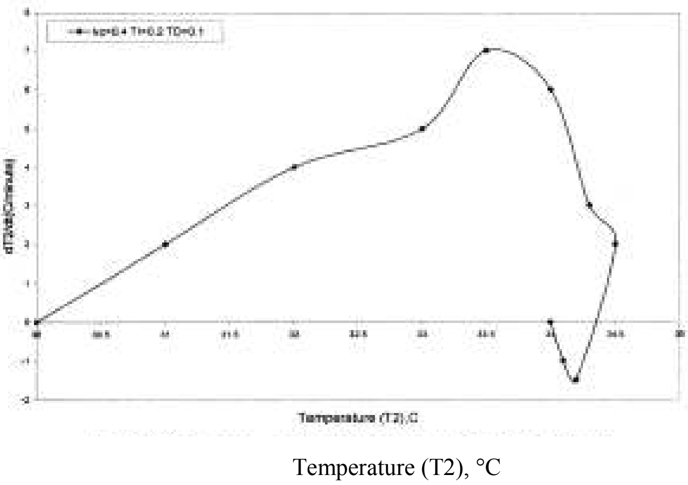


Figure (5): The phase-plane of the system for PID control

In the case of PID control with optimum setting (kc:0.4, TI:0.2 minute and TD: 0.1 minute) were selected according to Zeigler and Nichols criterion [7]. Fig (5) shows the offset is eliminated and the oscillation is rejected. So that, the phase plane shows the stable node portrait. The system with PID control shows no offset owing to the integral action, and the stabilizing effect of the derivative which allows the controller gain to be increased, reducing the maximum deviation and increasing the speed of response compared to P and PI controls.

Conclusions

1. The outlet temperature of the cold stream is the controlling variable. The instability of the PHE is due to insufficient heat transfer between cold and hot streams.
2. The experimental phase plane is better than other analytical methods for highly nonlinear PHE in the case of limiting the stability conditions.
3. The stability of the system is achieved by the PID control.
4. The accuracy of the phase technique can be increased by increasing the detectors of the process variables which are implemented with on-line digital computer.

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