Aspects regarding at $^{13}$C isotope separation column control using Petri nets system

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Abstract. This paper is intended to show that Petri nets can be also applicable in the chemical industry. It used linear programming, modeling underlying Petri nets, especially discrete event systems for isotopic separation, the purpose of considering and control events in real-time through graphical representations. In this paper it is simulate the control of $^{13}$C Isotope Separation column using Petri nets. The major problem with $^{13}$C comes from the difficulty of obtaining it and raising its natural fraction. Carbon isotopes can be obtained using many methods, one of them being the cryogenic distillation of carbon monoxide. Some few aspects regarding operating conditions and the construction of such cryogenic plants are known today, and even less information are available as far as the separation process modeling and control are concerned. In fact, the efficient control of the carbon monoxide distillation process represents a necessity for large-scale $^{13}$C production. Referring to a classic distillation process, some models for carbon isotope separation have been proposed, some based on mass, component and energy balance equations, some on the nonlinear wave theory or the Cohen equations. For modeling the system it was used Petri nets because in this case it is deal with discrete event systems. In use of the non-timed and with auxiliary times Petri model, the transport stream was divided into sections and these sections will be analyzed successively. Because of the complexity of the system and the large amount of calculations required it was not possible to analyze the system as a unitary whole. A first attempt to model the system as a unitary whole led to the blocking of the model during simulation, because of the large processing times.

1. Introduction

Petri-nets (PNs) are being grow up in aspects of their applications in the modeling, analysis and control of discrete manufacturing systems [1].

The aim of PNs is to model concurrent, synchronized interactions within a manufacturing system has contributed to their development as an important modeling tool.

PNs describe a manufacturing system graphically, and this contributes to a better understanding of the complex interactions within the system [1].

Since then, PNs have been modified, extensions proposed and detailed theoretical analysis performed. PNs are a "model for procedures, organization and devices where regulated flows play a role" [2].

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In modeling of the process using PN, independent events and causal dependencies are represented explicitly by introducing concurrent relations, which form the conceptual basis of net theory [3]. Systems can be represented at various levels of abstraction using the same descriptive language. PN representations allow for system-property verification in a systematic manner.

On the basis of supervisory model, the issues of safety verification, optimization of control parameters and scheduling of operating sequences are discussed.

At last, a distillation column is used as an example for modeling and analysis. Referring to a classic distillation process, some models for carbon isotope separation have been proposed, some based on mass, component and energy balance equations, some on the nonlinear wave theory or the Cohen equations.

2. Model of $^{13}$C isotope separation column

The separation column used for experiments can be configured in two ways: one - two columns of different diameters placed one within the other extension, and second way, one column with set diameter [4,5].

The main parts of the column are:
- The boiler of Primary column B1
- The boiler of Final column B2
- Vacuum jacket, M
- Aggregates vacuum, PVP (PD)
- Condenser- C
- First column C1
- Final column C2

In the column, using liquid nitrogen boiling at atmospheric pressure, the condenser (C) provides the reflux process to the top of the column with total condensation of carbon monoxide. The condenser from separation column is cylindrical and is provided with longitudinal fins.

It has the composition made of stainless steel, mono-block design. It measurements are: length is 800 mm and a diameter of 200mm.

Fluid flows gravitational from the condenser C1 on the column packing in counter current with monoxide carbon gas. In the first column, part of the liquid is vaporized and sent to the condenser and the other part enters into column C2. At the base of the column, the boiler B2 ensures the reflux process of carbon monoxide liquid [7, 8].

Column C1 has diameter 26mm and length 2500mm. Feed point divides the column in two enrichment sections: one of 1000 (1500) mm and second one dilution section of 1500 (1000) mm. It is filled with spiral triangular 2x2x0, 2mm stainless steel wire.

Column C2 has 16mm diameter and 4250mm length. It is filled with spiral triangular 1.8 x 1, 8x0, 2mm stainless steel wire (figure 1).

Boilers, B1 and B2 are heated by electrical resistance, which can have a maximum power of 100W and 50W.

The main component of an isotope distillation process is separation column, because in the column, using the contact between the two phases - the liquid and vapor, takes place the isotopic enrichment [6,8].

Our $^{13}$C experimental separation column is connected in its upper part, with liquid nitrogen-cooled condenser at atmospheric pressure (77 K) and at base on the boiler, which ensure the vaporization of the liquid. It operates at a temperature of about 79 K.

Column height is 7062 mm and is made also from stainless steel. In this model it was considered two columns: one with diameter of 16 mm and one with diameter of 26 mm, both the same height [8].

3. Model of a Petri Nets in industrial process

A Petri network type Location / Transition of the form [11, 12].

$$\sum = (P, T, F, W)$$ (1)
where:
- $F \subseteq (P \times T) \cup (T \times P)$ is a binary relation, called flux network relation,
- $W : F \rightarrow N$ is the weight function of the network $\sum(W(f))$ is called the weight of the element $(f)$.

Figure 1. Model of separation column in distillation process [7].

Let (1) a network type location / transition, is called network marking $\sum$ any function $M : P \rightarrow N$ with the property $M(p) \leq K(p)$, for any $p \in P$, where $K : P \rightarrow N \cup \{\infty\}$ is the function of network capacity $\sum$.

Let $\sum = (P, T, F, K, W)$

The network $P/T$, where you get

$N^P = \{M \mid M : P \rightarrow N \land (\forall p \in P)(M(p) \leq K(p))\}$

If the network has only infinite capacity, then $N^P$ coincides with the set of applications from $P$ to $N$. 
A marked P/T network is a pair \( \gamma = (\Sigma, M_0) \), where \( \Sigma \) a support is network of the \( \gamma \) network, and \( M_0 \) is the initial marking of the \( \gamma \) network. [3, 11, 12].

For \( \Sigma \) network transitions, considered functions \( t^-, t^+ : P \to N \) and \( \Delta t : P \to Z \) defined by:

\[
t^+(p) = W(p, t), \quad t^-(p) = W(t, p), \quad \Delta t(p) = t^+(p) - t^-(p), \quad \text{for any } p \in P.
\]

If \( w \) is known \( (w \in T^\star) \), is considered the function \( \Delta w : P \to Z \) given through the relation:

\[
|\Delta w(p)| = \begin{cases} 0, & \text{if } w = \lambda, \\
\sum_{i=1}^{n} \Delta t_i(p), & \text{if } w = t_1t_2...t_n, (n \geq 1), \text{for any } p \in P.
\end{cases}
\]

In the dynamic evolution of a network there are known three types of semantics [11]:

1. **Sequential evolution of the network** \( \gamma \) is given by the rule of transition, which consists of:
   
   -(RA – rule of applicability), transition \( t \) is possible by marking \( M \) in \( \Sigma \) and is noted \( M[t]_{\Sigma} \) if this relation takes place [11]:
   
   \[
   W(p, t) \leq M(p), \forall p \in P
   \]
   
   and
   
   \[
   M(p) + W(t, p) \leq K(p), \forall p \in P
   \]

   -(RC – rule of calculation), \( M' \) marking is produced by the appearance of transition \( t \) at \( M \) marking and is noted \( M[t]_{\Sigma} M \), if \( M[t]_{\Sigma} \) and
   
   \[
   M'(p) = (M + \Delta t)(p), \forall p \in P
   \]
   
   or
   
   \[
   M' = M + O(t) - I(t).
   \]

2. **Concurrent evolution relative** is the simplest way to capture the appearance of concurrent application of a transition. This method consists in generalizing the concept of "step" by moving from a transition to other transitions that can be applied concurrent to marking [10].

3. **Process type evolution**, type subset doesn't point out the concurrently aspects like the concurrent application of a transition to itself. And so it is introduced the concept of process of a network using finite limited appearances networks.

Invariants are a formal method of analysis Petri networks which was introduced by Lautenbach, additional information [10, 11].

This method is used to demonstrate the dynamic properties of Petri networks and accessibility, limitation, reversibility and durability properties. An advantage of invariants is that they can be built during the system design phase, thus achieving efficient modelling. These methods are used to demonstrate certain structural and dynamic properties of the analysed system [12].

Using (1), network P/T. \( |P| = m \), \( |T| = n \). Matrix \( m \times n \) defined by

\[
A(p, t) = O(t, p) - I(p, t)
\]

is the matrix of incidence of the network \( \Sigma \).
\( A(t, t) \) defines the state change of all locations after the production transition \( t \). Analogy is noted by \( A(p, \cdot) \), defines induced changes in location \( p \) by the production of all transitions.

The markings can be regarded as \( m \)-dimensional column vectors. A marking produced by the production of transition \( t_j \) at the \( M \) marking can be calculated with:

\[
M' = M + A \cdot f
\]

where \( f \) is a \( n \) dimensional vector that has 1 in line \( j \) and 0 everywhere else.

4. Model of a Petri Nets in \(^{13}\text{C} \) isotope separation column. Structure of Petri model \(^{13}\text{C} \) isotope separation column

It is used Petri nets in our \(^{13}\text{C} \) Isotope Separation column for control the (figure 2):

- Condenser- C
- The boiler of final column B2
- Vacuum jacket, M [8, 9]

The set of concrete systems and the multitude of their conduction problems have created a variety of mathematical representations, called models (figure 3).

Their variety is determined mainly by the structure of "object" analysed, by the scope of the research and by information available (figure 4, 5).

Figure 2. Petri net model applied on \(^{13}\text{C} \) Isotope Separation column.

Figure 3. Evolution of the Queue Length indicators corresponding to the positions analysed (continues line – current value. dotted line - global value resulted from mediation within the simulation interval).
5. Conclusions

This model system is using the Petri nets for discrete case event systems. In use of the non-timed and with auxiliary times Petri model, the transport stream was divided into sections and these sections was analyzed successively.

Due to the complexity of the system and the large amount of calculations required it was not possible to analyze the system as a unitary whole. A first attempt to model the system as a unitary whole led to the blocking of the model during simulation, because of the large processing times.

Like a future work it is intended to continue and make other model using Petri nets for distributed systems.

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