PRINCIPLES OF SUSTAINABLE PROCESS INFORMATION SYSTEM NETWORKS IN NIGERIAN PETROLEUM INDUSTRY

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ABSTRACT

Applying process kinetic models to process networks provide data useful for decision making in the task of synthesis, analysis and optimization. This requires that process networks be arranged and structured for increased efficiency, achievement of minimum cost and sustainable development. The various methods that could be exploited for process network arrangement are degrees of freedom, visual model, graph theory and the pinch technology for the various network types: Tree topology, cyclic network, spanning tree and its matrix representation. Among these, the optimal structure for cyclic network is the spanning tree which could be applied to large process networks. In Nigeria, process information systems (PIS) hardly become fully depreciated before they malfunction. This is due to inefficient process information system networks (PISN). Frequent repairs are capital intensive and hence companies liquidate much faster. Considering the present call for amendment of the Nigerian Petroleum Industry Law, it is recommended that every Nigerian industry meet a minimum standard in its process information system networks before being allowed to operate in Nigeria.

KEYWORDS: *Process networks; Information systems; Topology; Process models; Sustainable development.*

1.0. INTRODUCTION

There are cases of enormous losses due to failure of process information system networks. To mention just a few, a process plant that failed after seven years of operation because materials can no longer flow from one process unit to the other was found to be the result of process information system failure and not depreciation. Process plant data disharmonious with quality control laboratory result was found to be due to poor process information system network and not wrong laboratory procedure. This of course could result in undesired product quality and poor yields.

In Nigeria, process information systems (PIS) hardly become fully depreciated before they malfunction. This is due to inefficient process information system networks (PISN) (Maru *et al.,* 2000).

Frequent repairs are capital intensive and hence companies liquidate much faster. Process network must be made to be sustainable i.e. it must be passed onto future generations. Sustainable development is defined in Sampson (2016a) as development that meets the need of the present without compromising the ability of future generations to meet their own needs.

Various problems encountered in the industries are embodiment of information which if uncovered may not only enable the engineer solve the problems easily but can engender the type of understanding that will stimulate him to find better and more cost effective solutions.

Therefore, the objective of this study is to provide an insight into the Array of scientific tools available to the engineer to put value of his work as a process designer and analyst. With the integration of ICT (information and Communication Technology) into various levels of operations in the industry, the engineer should be able to seek, acquire and generate information through organized and systematic methods as well as adopt approaches which are amenable to the use of the vast power of the computer.

Linnhoff & Turner (1980) defines process network as a collection of related physical units and the facilities that provide links between them. The arrangement has a structure which is referred to as network topology.

Davies (1974) make Information flow to be understood by taking a look at Data communication and process information system.

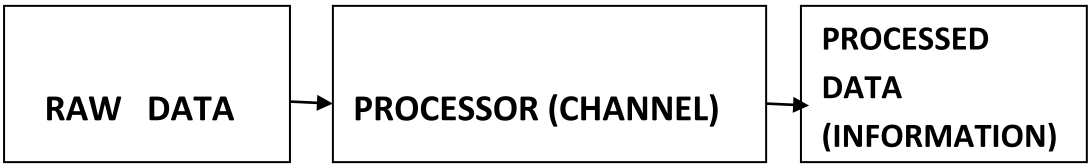


Fig. 1: A Simple Data Communication Network

Figure 1 is a simple Data communication network where data is processed into a form which is meaningful to the recipient and is useful for making decision. In this connection, information flow may be defined as data in motion. Similarly, a simple chemical process network is illustrated in figure 2. It consists of a process unit where input materials are converted into products.

Raw materials Finished products
C, T, P, H etc. C, T, P,H etc.

Fig. 2: A Simple Process Network

The input materials and the products are characterized by unique properties such as composition (C), temperature (T), pressure (P), enthalpy (H), flow rate (F) etc. In creating a chemical process information system (CPIS) the characteristics of the input-output materials are represented in the form of variables e.g. x_1, x_2, x_3 and y_1,

y_2, y_3 etc. respectively, while the physical process units are replaced by design models i.e sets of mathematical functions which establish the relationship between the input – output variables. This is shown in figure 3. It may be noted that just as it is with the process network, the design models have a structure i.e the Problem topology which influence the types of values the input-output variables may assume.

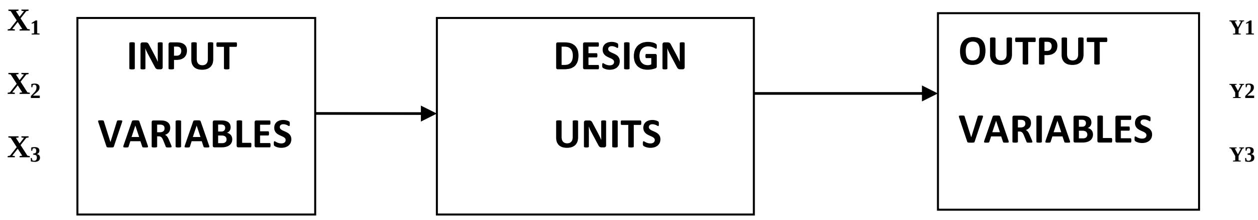


Fig. 3: Chemical Process Information System

Coulson *et al.* (1999) states that Information flows in the process system are therefore the values of the variables which are involved in the design models. The Engineer in the process industry is faced with the task of designing a new plant and operating and improving the existing one. The common activities in all these include synthesis, analysis and optimization. In process Synthesis, the engineer is concerned with the choice and assembly of units into functional systems and also searching for better alternatives. Analysis is the process by which the engineer simulates and evaluates the performance of the system to establish whether it satisfies the specification requirements. Then the optimum values for some key variables are sought to arrive at favorable economic indices while striking a balance between the competing factors affecting the process.

Several difficulties arise in the course of process design and operation of process plants due to the complexities of their networks, for even the most optimally designed units if inappropriately put together, may fail to function satisfactorily as a system. The relationship between process topologies and information flows offers a great opportunity to deal with these problems. Sampson (2016b) explains that due advantage of this relationship can be exploited through the use of information based technologies such as process integration, Enterprise Resource Integration (ERI) involving systems approach and scientific methodologies, computer application and communication technologies such as enterprise resource integration (ERI) and Automatic process control (APC). The benefits of efficient Process Information System Network (PISN) include productivity gain, better decision making, choosing the right alternatives given close options and making the right decisions. Sampson (2016b) cautions that Enterprise Resource Planning (ERP) and supply chain management systems are useful for obtaining cost and production information but if that information is not used to change business practices, poor business practices will be automated. Plant-centric approach to plant information systems provides the information necessary to improve safety and reliability through asset management capabilities.

2.0. METHODS

2.1. Conventional Approach

Himmelblau & Biscoff (1974) considers the requirement to link seven centres shown as in Figure 4a, together to form a Network with each link attracting appropriate cost.

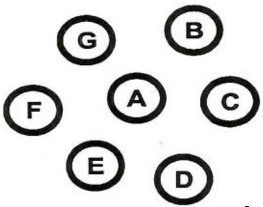


Fig. 4a: Centres to Link

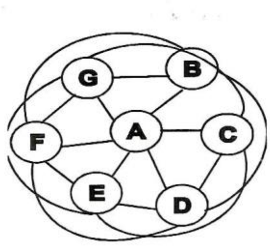


Fig. 4b: Stochastic Structure

An attempt to link the centres as in fig. 4b can create a very large number of combinations and it may not be possible to exhaust all the options even with the use of a computer. Although a useful configuration may be obtained by trial and error there is no insight gained into the nature of the problem.

2.2. Alternative Approach Based on Synthesis and Analysis

Suppose a structure is proposed as shown in figure 5a, with the figures indicating cost of the lines. Six links to connect the centres are given in figure 5b.

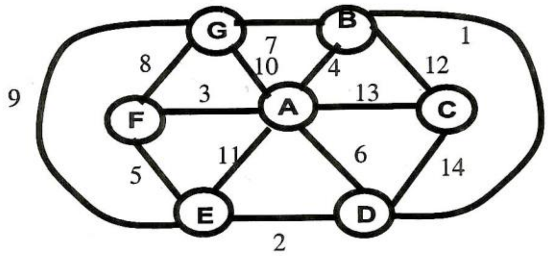


Fig. 5a: Ordered Structure

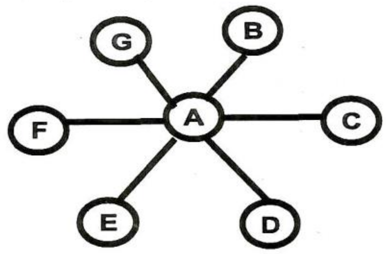


Fig. 5b: Centre Links

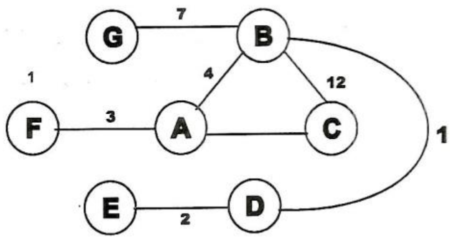


Fig. 5c: Alternative (I)

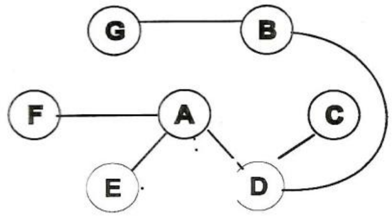


Fig. 5d: Alternative (II)

Unlike the conventional method in figure 4b, a pre-determined strategy can be followed to solve the problem. First, list out all the links and their costs, then decide to have a network devoid of cycles. By so doing, networks shown in figures 5c and d are obtained. In this alternative approach information provided by the network structure is utilized to arrive at a more efficient method of solving the problem.

The procedure helps find more than one network which can be evaluated and compared for arriving at a better choice. Also, the engineer and not the computer is in control and he feels more confident about his design.

2.3. Heat Exchanger Design and Analysis

The problem of choosing design variables in process design and analysis is well known in process engineering. The cooler in Figure 6 is given here as a typical example.

A cooler is a heat exchanger employed to reduce the temperature of a hot stream to the level required by the process. The solution is normally commenced by analyzing the degree of freedom where the number of variables and the design relationships are key inputs. The procedure is explained below.

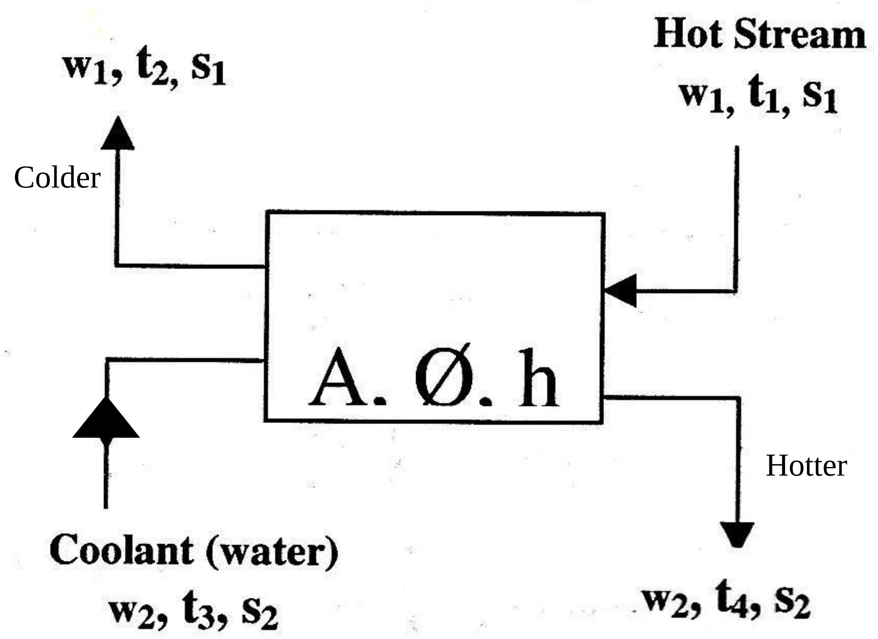


Fig. 6: Heat Exchanger

Mathematical Model for Heat Exchanger

$$\mathbf{Q = hA\,\Delta t} \qquad (1)$$

$$\Delta t = \frac{(t_1 - t_4) - (t_2 - t_3)}{\mathrm{In}\frac{t_1 - t_4}{t_2 - t_3}} \qquad (2)$$

$$h = f(\emptyset, t_1 \ldots, t_4, w_1, w_2) \qquad (3)$$

Heat Balance

$$w_1 s_1 (t_1 - t_2) = w_2 s_2 (t_4 - t_3) = 0 \qquad (4)$$

$$Q = w_1 s_1 (t_1 - t_2) \qquad (5)$$

Where:
Ø - type of cooler; w_1, w_2 - flow-rate of hot stream and water respectively; t_1, t_2 and s_1 – initial and final temperatures and specific heat of hot stream, t_3, t_4 and s_2 – initial and final temperatures and specific heat of water.

2.4. Degree of Freedom Analysis

Number of variables	M = 11
Number of equation	N = 5
Degree of Freedom	F = 11 – 5 = 6

- **Task: Selecting 6 variables such that the solution would be efficient and simple.**
- **No of ways $11C_6$ = 462 ways!**

$$MC_F = \frac{M!}{N!(M-N)!} \quad \textbf{(6)}$$

$$= \frac{11!}{6!(5!)} = \frac{39916800}{86400} = 462 \text{ ways}$$

From the analysis, some 5 variables can be calculated while 6 variables are to be selected which can be carried out in 462 ways. But a look at the information flows may reveal that some variables (W_1, t_1, t_2 and t_3) are fixed by process conditions, thus leaving us with two variables to choose. A good choice can simplify the calculations while a wrong one can complicate them.

For a hand calculation this problem may not easily be discerned because the designer's intuition can help and through several trials may arrive at the right solution. However, if a machine computation is to be preferred there is no such intuition and the problem implies recycling of information.

2.5. Visual Model – An Alternative method of selection

Entering variables are variables fixed by process conditions whereas leaving variables are calculated from model equations.
Consider a Visual representation.

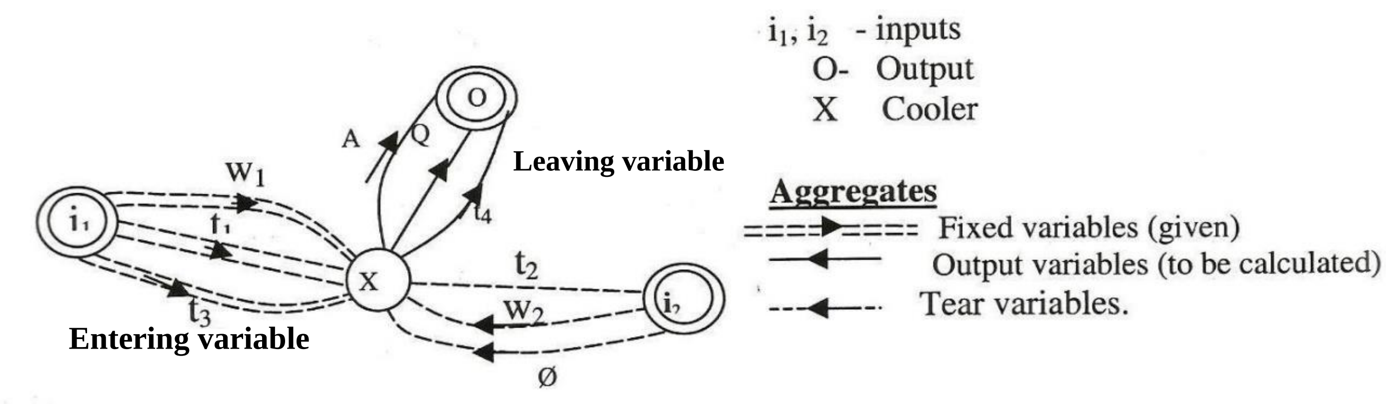


Fig. 7: Information Flows in a heat exchanger

Degree of Freedom

In figure 7, a visual representation of the heat exchanger design problems is shown. The visual model illustrates clearly the variables in the design model which are depicted by the information flows entering and leaving the cooler "X". The information flows – "i" entering "X" represents the variables fixed by the process conditions while those leaving "X" i.e. "O" are the variables to be calculated directly from the model equations. The remaining variables which should correspond to the degree of freedom are those which should be found for the solution to be complete.

Degree of freedom = No. of variables – No. of equations. **(7)**

Remaining variables = No. of variables – No. of equations **(8)**

The visual model shows that to proceed some values for the remaining values need be supplied i.e. now shown in figure 7 as revised information flows – "i_2", which process is equivalent to selecting tear variables for the design model.

Thus by using this simple visual model the designer has been greatly helped to arrive at choices which are scientific and it can easily be seen that, w_2 and $\emptyset$ which are so chosen are good. This is analogous to reducing the number of trial calculations.

In the above two examples, the difficulties associated with the solution of problems has been highlighted through conventional approaches. A peep into the use of topological analyses as alternative methods to provide an insight into problem structures has been done. By taking advantage of information flows associated with the structures, it has been possible to approach the solutions more efficiently.

In all these, some principles from area of mathematics called **graph theory** is used and gains so far listed as follows:

(i) Generation of only essential networks from a multitude of possible options.
(ii) Development of appropriate strategy for selecting the most optimum and cost effective networks.
(iii) Development of calculations strategy which is more efficient and stable and which reduces computational times.

2.6. Graphical Method

Network topologies manifest themselves in various forms in the process industry and the task of design, analysis and optimization can be greatly facilitated by using the results from graph theory.

2.6.1. Definition

The Graph G, is a set of vertices **V** $(\mathbf{v_1, v_2, \ldots, v_n})$ – nodes, points, elements, streams, subsystems, events, etc. and a set of lines connecting certain pairs $E(e_1\ e_2\ldots\ e_n)$ – streams, flows etc.

2.6.2. Types of Graphs

Graphs may be connected or unconnected. In figure 4a earlier shown, are unconnected points graph while Figures 8a and b are connected graphs. Graphs connected without directions as in Figure 8a is undirected graph while that connected with directions as in Figure 8b is a directed graph (digraph). In undirected graphs lines between the vertices are called paths while in directed graphs they are called arcs.

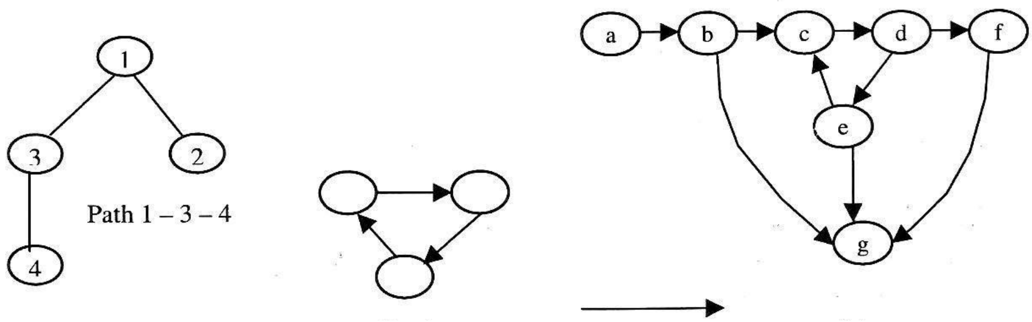


Fig. 8 (a) Undirected Graph (b) Directed Graph (Digraph)

2.6.3. Some Helpful Properties of Graphs

2.6.3.1. Isomorphous Graphs

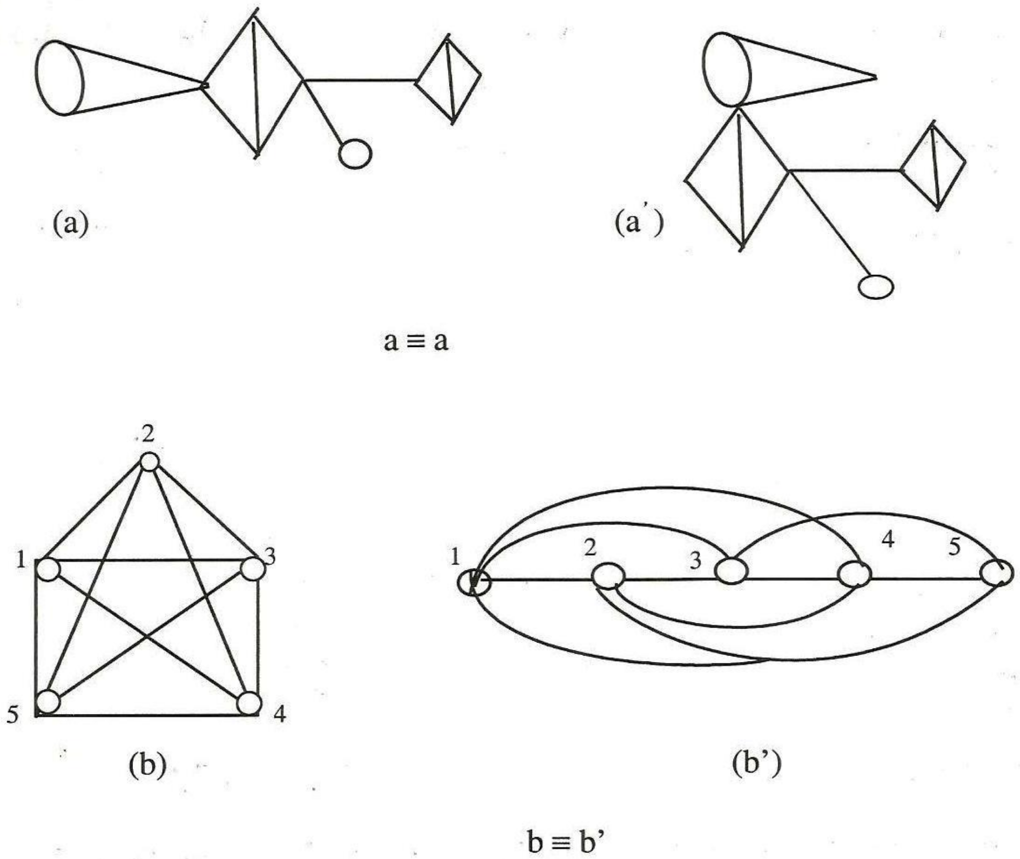
Mathematical Representation

Steward (1987) explains that two graphs G = (V^1, E^1) are isomorphic when there is one to one correspondence $V \leftrightarrow V'$, $E \leftrightarrow E'$ such that if

$(v_{i,}\ v_i)\ \epsilon V \leftrightarrow \left(V_i', V_j^1\right) \epsilon\ V'$

Then the edge: $e = (e_I, e_I) \in E \ \leftrightarrow e' = \left(e_i^I, e_j^I\right) \epsilon\ E'$ **(9)**

2.6.3.2 Graphical Representation



Figs.9: Isomorphic graphs

Examples of pairs of isomorphic graphs $a \equiv a'$ and $b \equiv b'$ are shown in Figure 9. The graphs have the same number of vertices with each pair of vertices connected to edges of the graph corresponding to those of the second graph.

2.6.3.4. Applications of grahs

(i) Basis of representing the physical process network of topologies in graph form.

(ii) Number of control measurements for a process can be reduced as measurements for one set of vertices or nodes of one graph which model it can represent the corresponding ones in the second graph.

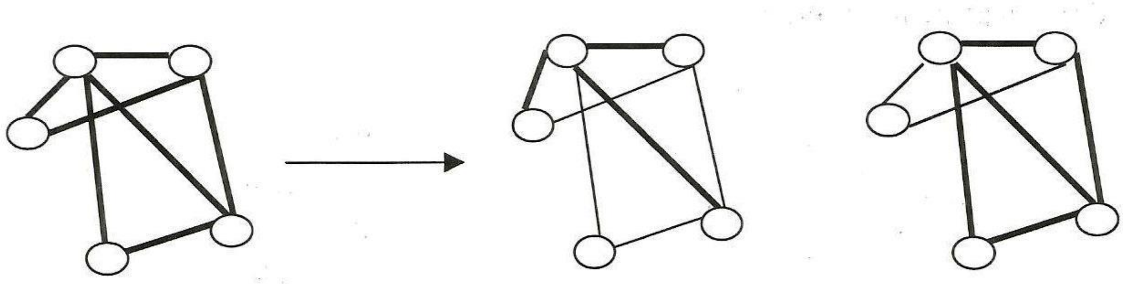
(iii) Basis for locating data to be reconciled.

2.6.3.5. Sub-graphs and Network Decomposition

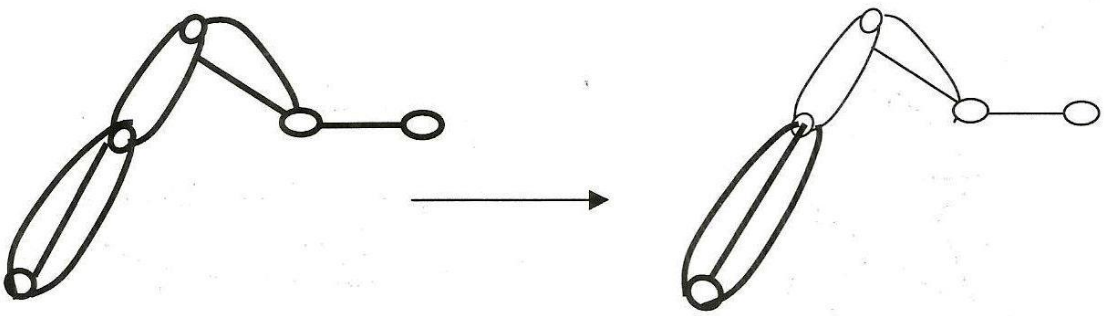
The sub-graph of G is the graph in which all vertices and edges belong to G i.e. G' = (V,E') is the subgraph of G = (V, E), if $V' \subseteq V, E' \subseteq E$ **(10)**

and edges connect vertices V'. where ⊆ means contained in or equivalent to.€ means element of a set.

Figure 10 shows the sub-graphs G_I and G''_I and sub-graph G_2' of graph G_2.



Graph G_1 Graph G_1' Graph G_1''



Graph G_2 Subgraph G_2'

The subgraphs are composed of subsets of the vertices and subsets of the edges of the complete graph. Koryachko (1970) explains that to break a graph into its component parts is to split it at its cut vertices because at the cut vertices there is minimum interaction. This is illustrated in Figure 10. Analogous to this understanding, a process network may be decomposed on basis of subsystems having boundaries of least interactions. The boundaries may not be physical but can be created on the account of common information flows. Thus, it is possible to:

(i) Aggregate subsystems such as heat exchanger networks, water distribution networks and communication systems which satisfy certain specific needs of the process industry and analyze them conveniently as subgraphs of the overall process topology.
(ii) The subsystems may be treated as complete systems of their own where changes may be effected with minimum impact on the overall system i.e. without necessarily causing simultaneous changes elsewhere.

2.7. The Pinch Technology

An illustration of this is found in the example of a heat exchanger network where the understanding of pinch point decomposes the system into two parts, i.e. heat source and heat sink as shown in figure 11. Each part is complete on its own with no heat flow across the pinch under optimum conditions. The pinch provides the most optimum point from where to commence the design of the two parts for maximum efficiency. The concept of pinch technology is discussed in Mah (1982).

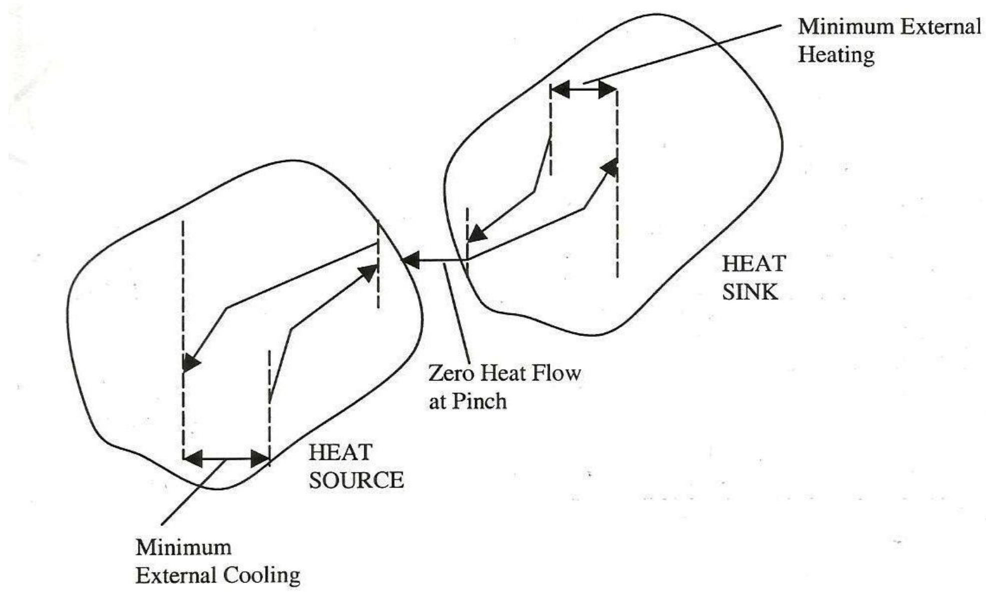


Fig. 11: Heat flow subsystems in Heat Exchanger Network

2.8. Networks Types

The types of network topologies and their specific applications:

2.8.1. Tree Topology

In the Example Problem 1, any link that tended to complete a cycle was rejected and connected graphs without cycles obtained. A graph without cycle is called a tree and its number of edges is equal to the number of vertices less one as expressed in equation.

$$E = v - 1 \tag{11}$$

Another feature of a tree is that there is only one path between every pair of vertices. The above characteristics of the tree have made its study a very interesting subject for optimizing the capital costs of the heat exchanger networks as demonstrated in Figures 12 and 13.

In figure 12, the grid form of the heat exchanger for benzol distillation plant is shown and figure 13 represents the network topology in graph. In the graph the edges are the units i.e. the heat exchangers, coolers and heaters while the vertices are the process and utility streams. On basis of the tree concept, the minimum capital cost for the exchangers from expression 6 should be obtained when the number of the exchanger units is 5 i.e. the number of streams less 1. But this is not so from figure 13a, rather it is 6 units because of implications introduced by a loop, (L) and the number of independent components, (S) i.e. (ST-C1-H2-CW-H3) and (C1-H2-CW). So the actual expression that should apply in this case is

$$E = V + L - S \tag{12}$$

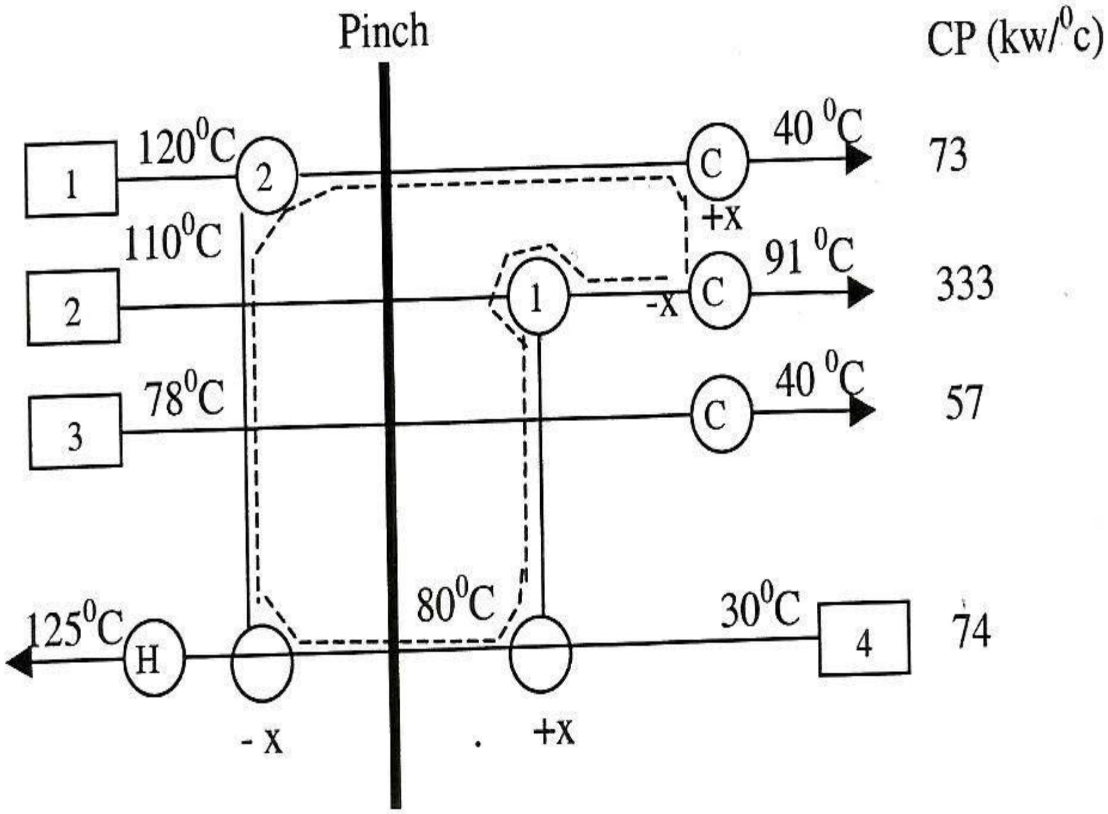


Figure 12: Heat Exchanger Grid

The loop is indicated with dotted lines.

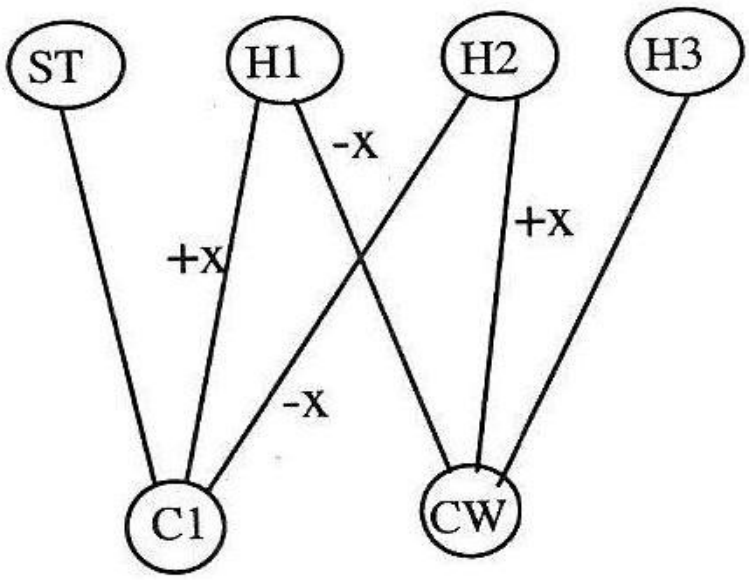


Fig. 13a: Heat Exchanger Network Topology

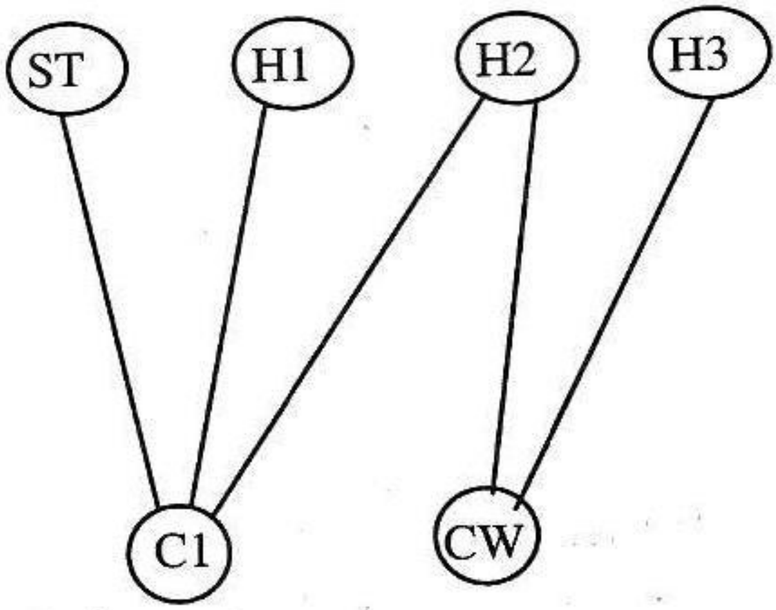


Fig. 13b: Improved Network Topology (no Loop).

To attain the minimum number of units, the loop as indicated by the dotted line in Figures 12 and 13a need be broken. The procedure is well established and has been shown in this example by shifting the loads "X" round the loop in Figures 12 and 13.

This is a very powerful tool in heat exchanger network design and analysis and by it the designer can among other things consciously redistribute the loads and thereby avoid matching streams which are prohibited on account of high cost of piping, safety etc.

2.8.2. Cyclic Networks

Earlier in the paper a tree was defined as a graph without cycles and examples have shown that a tree is a minimum cost network. The relationship between cyclic and tree networks can therefore be exploited for a more cost effective design of processes with similar topologies.

A cyclic graph G, and its subgraphs T_1 and T_2 are shown in Figure 14.

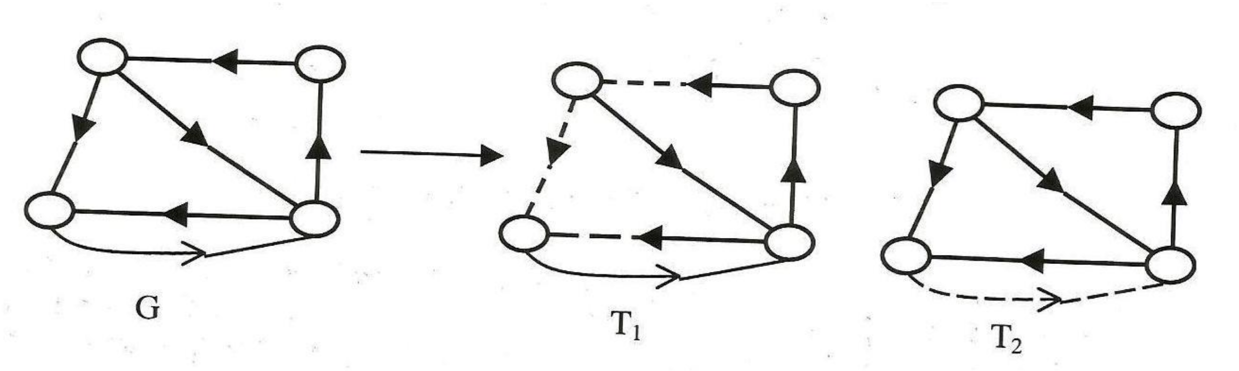


Fig. 14: Graphs and Corresponding Trees.

Subgraphs T_1 and T_2 are trees which may be found from G by tearing some chords. Generalizations from graph theory as are evident from figure 14 are:

(i) That all connected graphs contain tree and every cyclic graph contains at least one cycle.

(ii) To form a tree an edge (a chord) is broken which process continues until a tree is formed.

2.8.3. The Spanning Tree Method

In example shown in figure 4a, starting with centres without a fixed structure a network was synthesized. In other instances the network topology may be fixed right from the start and it may be required that the shortest paths be formed for each pair of vertices. These can be found by using a powerful tool called the spanning tree method. The procedure is based on systematically breaking chords until a minimum spanning tree is obtained. In a spanning tree, only one path exists between any two vertices in the network. The method is easily programmed for data processing on a computer. The procedure is shown in figure 15.

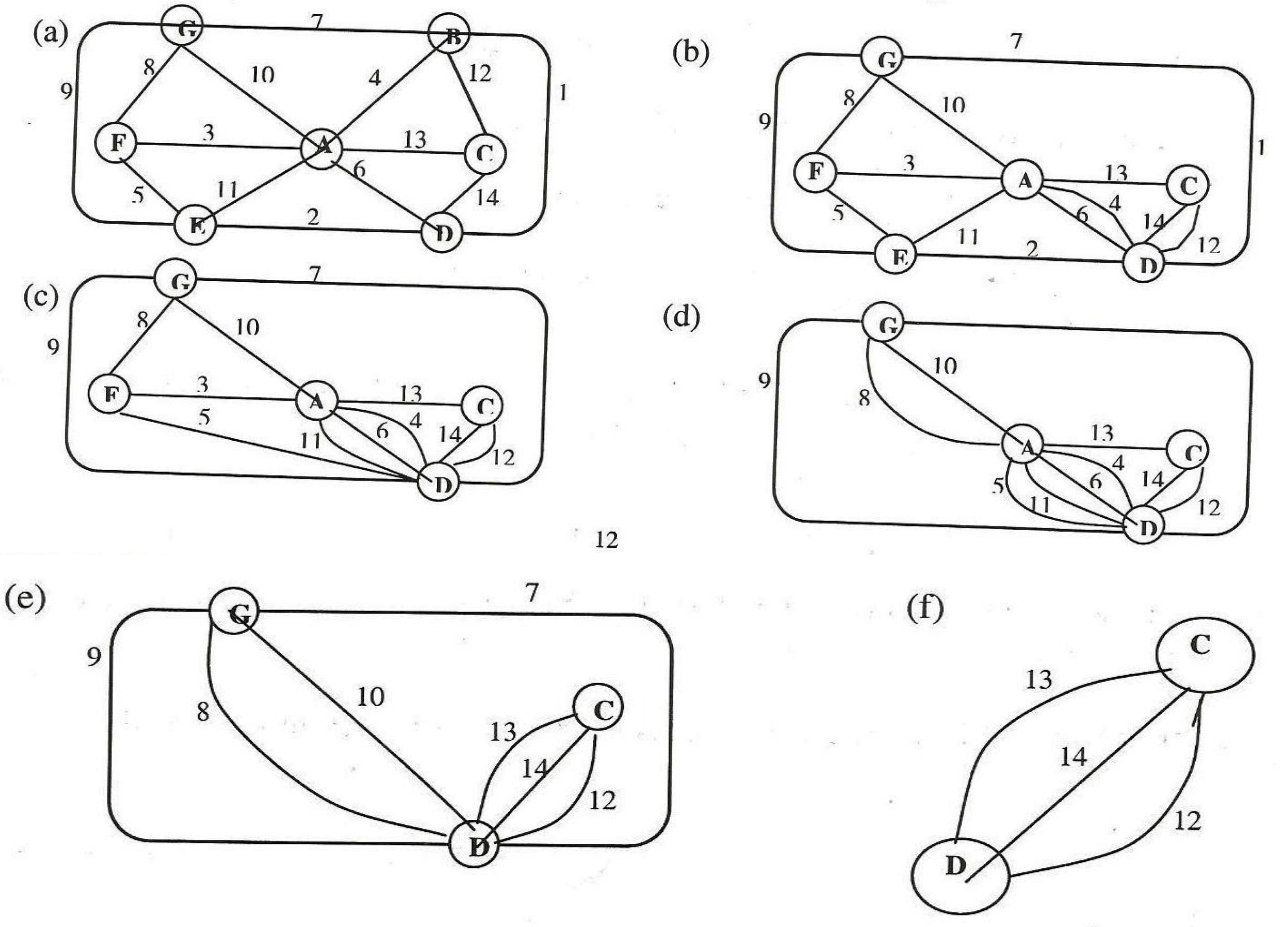
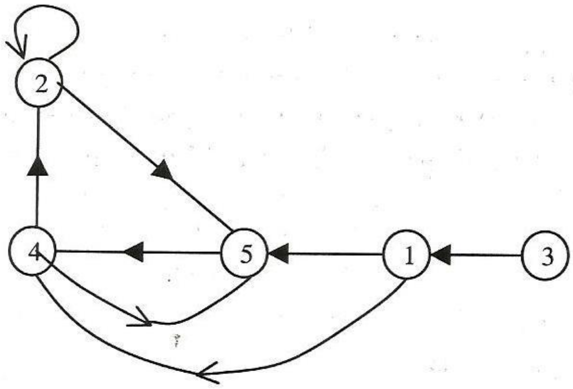


Fig. 15: Vertex Fusion Procedure

In this procedure, the cheapest edge is found followed by the fusion of the pair of vertices which it joins. Then the edges attached to the vertex that is removed are transferred to the surviving vertex. This goes on until all possible edges are selected.
In cases where there are no weighted values to guide in the tearing of chords, some heuristics have been developed which are helpful.

2.8.3.1. Matrix Representation

It is necessary to point out at this stage, that graphs are themselves veritable analytical tools until they become quite large when they lose their intuitive appeal. Related to graphs are Boolean matrices which can greatly enhance machine computations and data processing. Figure 16 shows a graph and the associated matrix.



$$R = \begin{vmatrix} 0 & 0 & 0 & 1 & 1 \\ 0 & 1 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \end{vmatrix}$$

Fig. 16: Graph and Corresponding Matrix

The elements of the matrix are formed by the rule:

$$R = r_{ij} = \begin{Bmatrix} 1, \text{if vertex i, is connected to vertex j} \\ 0, \text{if two vertices i and j are not connected to one another} \end{Bmatrix} \quad \textbf{(13)}$$

With this representation a lot of information may be generated which can aid the design and analysis of large scale systems.

2.8.3.2. Applications to large Process Networks

The method has been demonstrated on absorption plant involved in the removal of CO_2 from synthesis gas using monoethanolamine. The flow balances are found by using a procedure which decomposes the process network.

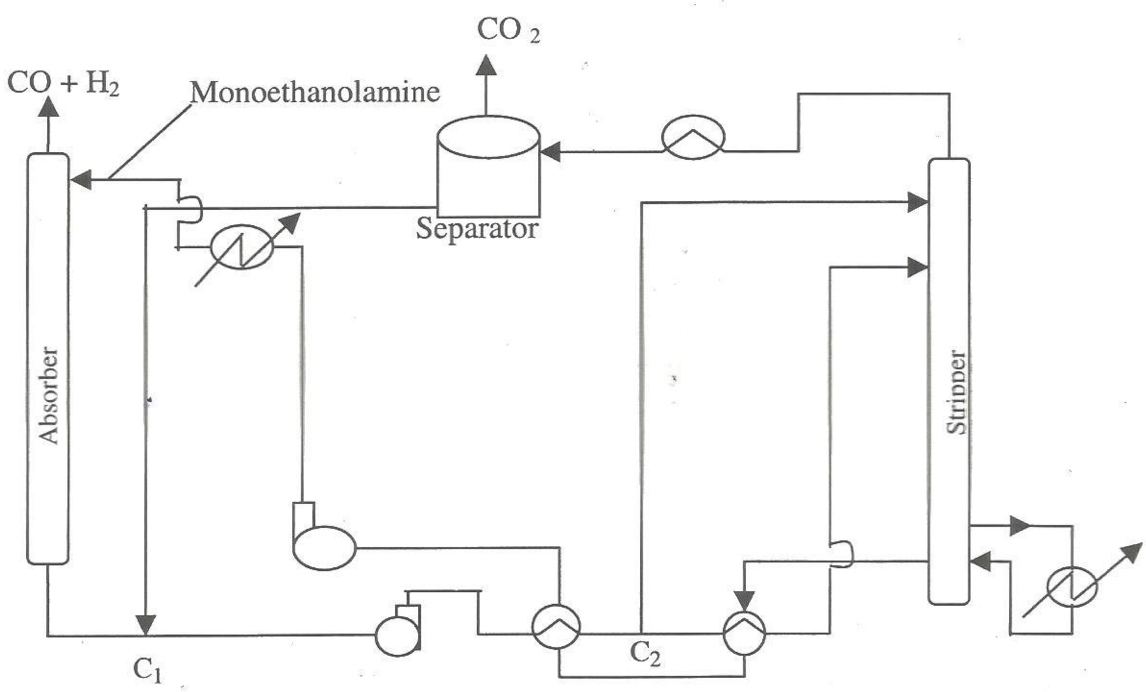


Fig. 17: Absorption of CO_2 from synthesis Gas using Monoethanolamine

It is well known that, in general the balance equations generated on basis of the law of conservation of mass and energy are non-linear. But it is possible to linearise them if either the overall flows or components are specified in which case each element (subsystem) of the system may be described by a linear balance equation.

For a network topology, the flow balance at each vertex may be defined by Kirhoff's first law which states that the algebraic sum of flows at each vertex must be zero. So by also applying the Boolean matrix principle the balance equation for each vertex will yields:

$$\mathrm{A \times R = 0} \qquad \textbf{(14)}$$

$$\text{Where } [\mathrm{A}] = [a_{ij}] = \text{Matrix of balance equations} \qquad \textbf{(15)}$$

$$\text{Such that, a} = \begin{Bmatrix} +1, \text{if the flow enters the vertex i from vertex j} \\ 0, \text{if the flow is not linked to the vertex} \\ -1, \text{if the flow leaves the vertex i to vertex j} \end{Bmatrix} \qquad \textbf{(16)}$$

R = the column matrix of the type of the generalized flow as earlier defined. **(17)**

Other criteria for setting up the Boolean matrix around each vertex may also apply.

2.8.3.3. Calculating the Balances

The flow graph of the CO_2 absorption system is given in figure 18, and each arrow is a directed flow of some quantity e.g. mass, heat, Naira etc.

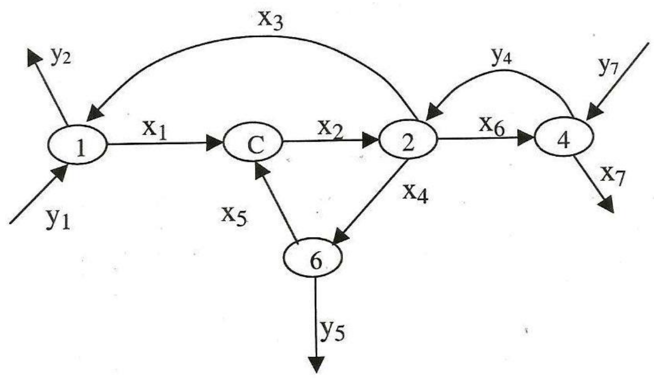


Fig. 17: Flow graph of the Absorption System

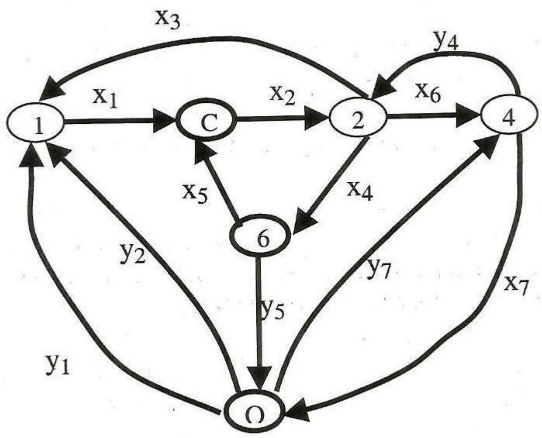


Figure 18 Cyclic Flow Graph.

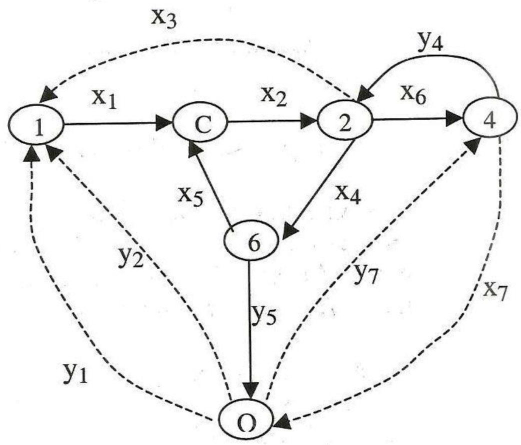


Figure 19 Spanning Tree of Cyclic Flow Graph.

To solve the problem, the status of the inlet and product streams are changed by introducing a hypothetical vertex known as 0 vertex where the streams are connected to form a cyclic flow network as shown in figure 19.

From the earlier discussions the optimal structure for the cyclic network is a spanning tree. To arrive at this structure, some fundamental loops (maximal cyclical nets) have to the identified as shown in Table 1. These correspond to the subgraphs concept of decomposing a network into sub-systems with the least interactions. The spanning tree structure is then found as in figure 20, by specifying some variables which are held constant (deleted from the list of variables) i.e torn from the cyclic network. These are represented by the dotted arcs (chords) in the figure 20. The remaining variables are the interface variables whose values must be found. By tearing we mean selecting certain output variables from a set of equations as known values so that the remaining variables can be resolved by several substitution.

A residual set of equations equal to the number of tear variables will remain, and if this is not satisfied, new guesses are made for the values of the tear variables and the sequence repeated. By analyzing the loops on the basis of incidence of the tear variables and also the directions of the interface variables.

Table 1: Loops and Associated Tear Variables

Loop	Tear Variable
L1	(y_1, x_1, x_5, y_5)
L2	$(y_2, x_1\ y_5, x_5, x_1)$
L3	(x_2, x_4, x_5)
L4	(x_3, x_1, x_5, x_4)
L5	(x_6, y_4)
L6	(y_7, y_4, x_4, y_5)
L7	(x_7, y_5, x_4, y_4)

Table 2: Relationship between Interface Variable and Tear Variables

Loop	Tear Variable
x_1	$y_1 - y_2 + x_3$
x_4	$x_2 - x_3 + y_7 - x_7$
x_5	$y_2 - y_1 + x_2 - x_3$
y_4	$x_6 + y_7 - x_7$
y_5	$y_1 - y_2 + y_7 - x_7$

LOOPS

		L1	L2	L3	L4	L5	L6	L7	
Tear Variables (Chords)	y_1	+1	0	0	0	0	0	0	= R
	y_2	0	+1	0	0	0	0	0	
	x_2	0	0	+1	0	0	0	0	
	x_3	0	0	0	+1	0	0	0	
	x_6	0	0	0	0	+1	0	0	
	y_7	0	0	0	0	0	+1	0	
	x_7	0	0	0	0	0	0	+1	
Interface Variables	x_1	+1	-1	0	+1	0	0	0	= A
	x_4	0	0	+1	-1	0	+1	-1	
	x_5	-1	+1	+1	-1	0	0	0	
	y_4	0	0	0	0	+1	+1	-1	
	y_5	+1	-1	0	0	0	+1	-1	

Figure 20: Incidence Matrices

The matrices R and A respectively in Figure 20 are obtained by using the Boolean matrix multiplication in equation 14, the balance equations in Table 2 are generated and the interface variables solved for.

3.0. Discussion

The arrangement of process information system networks is significant for sustainable development. Difficulties arise in the course of process design and operation of process plants due to complexities of their networks, for even the most optimally designed units if inappropriately networked may fail the future generations.

The various methods that could be exploited for process network arrangement are degrees of freedom, visual model, graph theory and the pinch technology for the various network types:

Tree topology, cyclic network, spanning tree and matrix.

Among this, the optimal structure for cyclic network is the spanning tree which could be applied to large process networks.

4.0. Conclusion

The relationship between various network topologies and the associated information flows have been examined. It has been demonstrated that the understanding of the problem and information structures are very helpful in deriving scientific methods for solving industrial problems. The theoretical framework for applying all the related principles has been elucidated.

5.0. Recommendations

The following recommendations are made:

(i) Considering the present call for amendment of the Nigerian Petroleum Industry Law (PIL) it is recommended that every process industry meet minimum standard in its process information system network before being allowed to operate in Nigeria.

(ii) Instead of the trial and error procedure of process system network design, a list of all links and their cost be made and the network made to be devoid of cycles so as to utilize information provided by the network structure to arrive at the most efficient, cost effective and sustainable solution to engineering design problems.

(iii) The Engineer consciously redistribute loads to avoid matching streams prohibited on account of high cost of piping, safety, etc.

(iv) The optimal structure of a cyclic network (the spanning tree) be obtained by identifying maximal cyclical nets, decomposing the network into subsystems with least interactions. By tearing constant variables (tear variables) from the cyclic network, the values of interface variables could be found.

6.0 NOMENCLATURE

ΔT	Change in temperature
A	Area of heat transfer
APC	Automatic Process Control
CI	inlet cooling water
CPIS	Chemical Process Information System
CW	Cooling Water
ERI	Enterprise resource integration
ERP	Enterprise resource planning
H_2	Outlet hot stream
H_3	Hot outlet of cooling water
h	Heat Transfer Coefficient
ICT	Information and Communication Technology
PIL	Petroleum insustry law
PIS	Process information system
PISN	Process information system networks

Q	Quantity of heat transferred
S	Number of independent components
ST	Stream
⊆	Contained in or equivalent to
ϵ	Element of a set

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