

Recycle, Reachability & Serial Calculation

Planning, Recycle & Serial & Reachability

The planning of calculations falls in two parts:

- Separating the units into those which form part of a recycle loop and those which are (or will be) directly calculable.
- Planning the calculation of each of the separate recycle loops.

Planning – Information Flow Diagram

- No recycle in Information Flow Diagram
- Unit can be calculated one after another starting from a unit which has only feed streams entering it.
- At least one such unit must exist otherwise there is recycle.
- All units can be sequentially calculated if and only if there is no recycle.
- A part of a process which has no recycle can also be called serial process and its units can be called serial set .

Reachability

- An output stream of a unit affects at least one of its input streams
- units of any IFD may be divided into two groups:
 - Serial sets
 - Recycle sets

Thus the plan of calculation of a process consists of :

- Identification of serial sets and recycle sets and placing them in a feasible calculation sequence.

- o finding how to calculate each recycle set

Identification of sets:

- 1) The process matrix method :

Table 3.1: Process Metrics

Unit number	Unit computation name	Associated stream numbers				
1	Mixer	1	2	-3		
2	Mixer	3	4	-5		
4	Mixer	5	6	7	-8	
5	Mixer	5	6	-7	-10	
6	Mixer	10	11	-12	-13	
8	Mixer	12	14	16	-15	
9	Mixer	15	17	19	-16	-18
10	Mixer	18	20	-19	-21	
11	Mixer	21	22	-23		

A unit can be calculated if all its inputs are known either because they are feeds or because they come from other units which can already be calculated. The unit 1 has only feed stream into it and thus can be calculated. This makes stream 3 known. Then unit 2 can be calculated because stream 3 is now known and stream 4 is a feed. But unit 4 cannot yet be calculated because stream 7 is not known even though streams 5 and 6 are now known and stream 6 is a feed. There are no more units which can be calculated among those remaining. Since some units remain uncalculated, the set composed only of units 1 & 2 has been identified.

Planning the calculations:

Calculation may be done by two ways:

- Sequential calculation
- Simultaneous calculation

Sequential calculations:

The process matrix can be used to find a workable sequence of calculation for a recycle set.

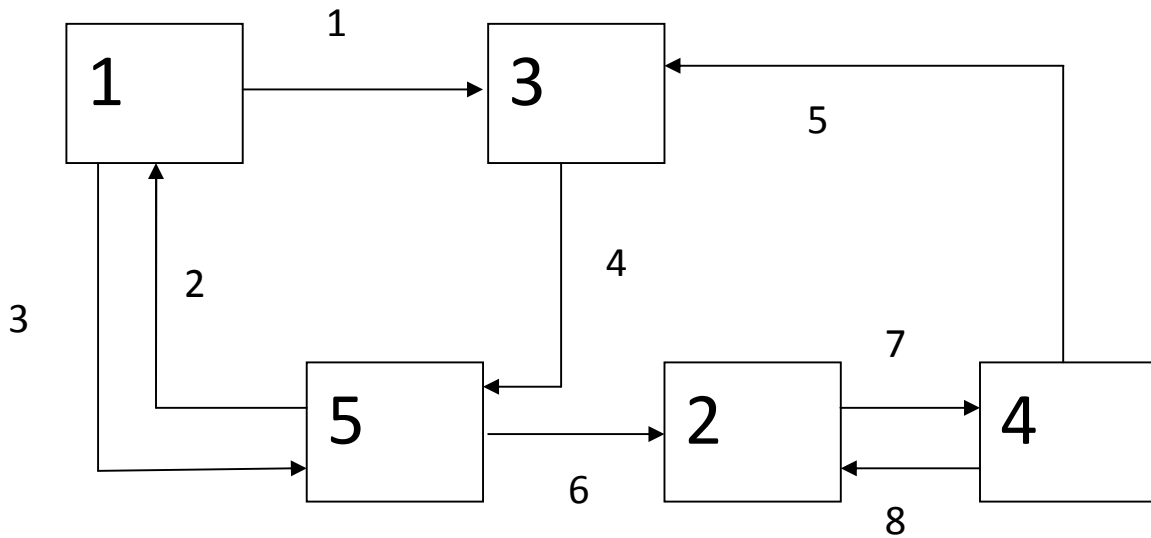


Fig 3.1: Process Flow Diagram

Table: 3.2: Process Metrics

Unit no	Unit compu. name	Associated streams			
1	UNIT1	2	-1	-3	0
2	UNIT2	6	8	-7	0
3	UNIT3	1	5	-4	0
4	UNIT4	7	-5	-8	0
5	UNIT5	3	4	-2	-6

The process matrix can be used to find a workable sequence of calculation for a recycle set by exhaustively searching among the streams of the recycle set.

From table 3.2, If stream 1 & 5 were known only unit 3 could be calculated. But if stream 2 and 7 were known the entire set could be calculated in the sequence (1, 4, 3, 5, 2)

The steam 2 and 7 are recalculated when units 5 and 2 are done so that the assumed values can be replaced by newly calculated ones and the sequence repeated.

If no pair of streams could lead to a complete calculation, then all combinations of three would be examined.

For large recycle sets the number of combinations of streams four or more at a time would be too large to want an exhaustive search for and arbitrary number of streams required to be assumed known.

For comparison, the recycle matrix of Lee & Rudd (1966) is applied to the same recycle set.

There are four loops which are (2, 3) , (7, 8), (1, 4, 2), and (4, 6, 7, 5). These loops can be represented in the cycle matrix given in the table, where rank of a loop is the number of streams in it and the stream frequency is the number of times a stream is in a loop.

Table 3.3: Identification of Recycle Loops:

Loop no.	Streams no.								Loop rank
	1	2	3	4	5	6	7	8	
1		1	1						2
2							1	1	2
3	1	1		1					3
4				1	1	1	1		4
Stream Frequency	1	2	1	2	1	1	2	1	

A minimum number of streams to be cut (assumed known) in order to eliminate all recycle can be found in the following manner. A stream is said to be contained in another j if each loop in which stream is found also involves stream j.

Thus stream 1 & 3 are contained in stream 2, streams 5, 6 & 8 are contained in stream 7 and 1, 5, & 6 are contained in stream 4. Since no more recycle loops

could be cut by any stream than by the stream which contains it, streams 1, 3, 5, 6, and 8 can be eliminated

Table 3.4: Remaining recycle loops:

Loop No.	Streams			Loop no.
	2	4	7	
1	1		1	1
2				1
3	1	1		2
4		1	1	2
Stream frequency	2	2	2	

Since a loop of rank 1 can only be cut by cutting the one remaining stream, streams 2 & 7 must be cut. Fortunately this breaks loop 3 & 4 at the same time. Therefore, assuming values for the variables of streams 2 & 7 will allow a direct calculations of all the unit of same fig. in the sequence (1, 4, 3, 5,2)

The Adjacency Matrix

The adjacency matrix is another tool for separating serial and recycle sets of units. The information flow diagram for fig. 3.2 is used as the example for the development of adjacency matrix and its adjacency is given in table 3.5:

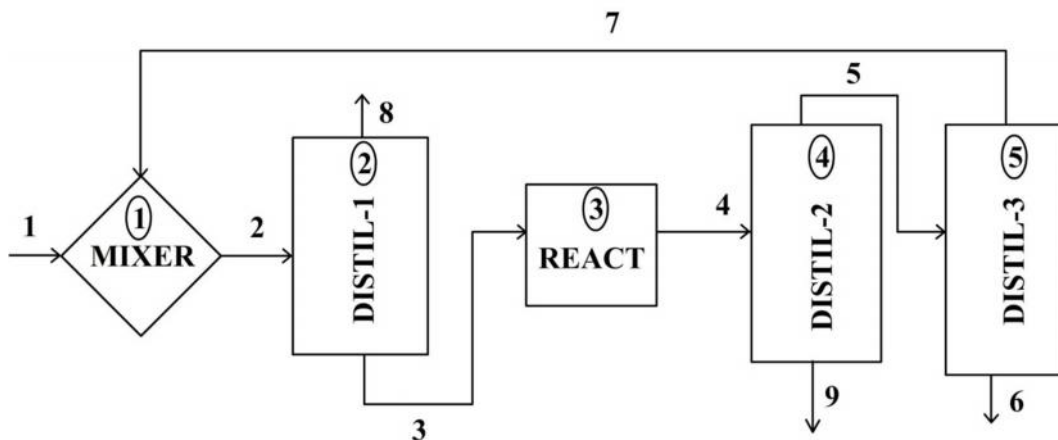


Figure: 3.2 Information Flow diagram of a typical mixing plant

Table: 3.5: Adjacency Matrix of a typical information flow diagram of figure 3.2

		To unit									
		1	2	4	5	6	8	9	10	11	
From unit	1		1								
	2			1							
	4				1						
	5			1		1					
	6						1				
	8							1			
	9						1		1		
	10								1		
	11										1

By definition there is unity in row i , column j of A (i.e. element $a_{ij}=1$). Suppose the column corresponding to a unit in A has only zeros as for unit 1 of above table this means that no unit is connected to unit 1 or in other words only feed stream enter unit 1 can be recorded in a list for later calculation and removed from A by striking out its column and its row then the reduced A becomes:

Table 3.6: Adjacency Matrix after deleting Rows & Columns

	2	4	5	6	8	9	10	11
2		1						
4			1					
5		1		1				
6					1			
8						1		
9					1		1	
10						1		1
11								

Once unit 1 is removed now unit 2 has a zero column and can thus be removed in a similar way. there are no more zero columns.

Suppose the row corresponding to a unit has only zeros as does unit 11 of the above table this means that unit 11 is not connected to any other unit and will be directly calculable . once all other units have been calculated then unit 11 may be recorded in list for later calculation in front of the previous found unit with a zero row. and so matrix A has been reduced to matrix A where all the remaining units 4, 5, 6, 8, 9 and 10 are either in recycle sets or in a serial set between a pair of recycle sets.

Table 3.7: Final Adjacency Matrix after deleting Rows & Columns

	4	5	6	8	9	10
4		1				
5	1		1			
6				1		
8					1	
9				1		1
10					1	

The same separation of initial and final serial sets has been achieved both by the process matrix and by adjacency matrix. The further unsaving of the remaining units into distinct recycle sets can be done directly by use of the adjacency matrix but only by exhaustive search using the process matrix

Identifying Recycle Sets : Powers of the adjacency matrix:

The reduced adjacency matrix A can be used to identify the different recycle sets and if desired the recycle loops within each set. If the recycle set is to be solved by treating all the units of the set simultaneously then it may not be necessary to identify recycle loops within the set. If the set is to be solved by sequential calculation of the units then the recycle loops may need to be identified.

The method of finding recycle sets and their loops requires finding the powers of the adjacency matrix by matrix multiplication. The useful property namely that the element of the product of two matrices A and B is

$$\sum_{k=1}^m a_{ik} b_{ki} \text{ with } a_{ik}, b_{ki} \text{ as the } (i, k) \text{ element of } A \text{ and } B \text{ respectively.}$$

The arithmetic is Boolean

Boolean addition:

$$0 + 0 = 0$$

$$0 + 1 = 1$$

$$1 + 1 = 1$$

Boolean multiplication:

$$0 \cdot 0 = 0$$

$$0 \cdot 1 = 0$$

$$1 \cdot 1 = 1$$

This is equivalent to using ordinary arithmetic and replacing all positive integers by unity. when the nth power of A has been found by (n-1)

successive multiplication of A with itself. It can be proved that A^n means that at least one path via n stream exists from the unit corresponding to column j. vice versa. A zero implies no such path.

If

A^n ($n= 2,3,\dots$) is generated for a recycle process, some diagonal elements of A^n will eventually become unity. But any unit i corresponding to a diagonal unity has a path via n streams from unit i back to i itself. i.e a recycle loop. All the recycle loops can thus be found

$$\begin{array}{rcccccc}
 & & \mathbf{4} & \mathbf{5} & \mathbf{6} & \mathbf{8} & \mathbf{9} & \mathbf{10} \\
 \mathbf{A} = & \mathbf{4} & & 1 & & & & \\
 & \mathbf{5} & 1 & & 1 & & & \\
 & \mathbf{6} & & & & 1 & & \\
 & \mathbf{8} & & & & & 1 & \\
 & \mathbf{9} & & & & 1 & & 1 \\
 & \mathbf{10} & & & & & 1 &
 \end{array}$$

$$\begin{array}{rcccccc}
 & & \mathbf{4} & \mathbf{5} & \mathbf{6} & \mathbf{8} & \mathbf{9} & \mathbf{10} \\
 \mathbf{A}^2 = & \mathbf{4} & 1 & & 1 & & & \\
 & \mathbf{5} & & 1 & & 1 & & \\
 & \mathbf{6} & & & & & 1 & \\
 & \mathbf{8} & & & & 1 & & 1 \\
 & \mathbf{9} & & & & & 1 & \\
 & \mathbf{10} & & & & 1 & & 1
 \end{array}$$

$$\begin{array}{rcccccc}
 \mathbf{A}^3 = & & \mathbf{4} & \mathbf{5} & \mathbf{6} & \mathbf{8} & \mathbf{9} & \mathbf{10} \\
 & \mathbf{4} & & 1 & & 1 & & \\
 & \mathbf{5} & 1 & & 1 & & 1 & \\
 & \mathbf{6} & & & & 1 & & 1 \\
 & \mathbf{8} & & & & & 1 & \\
 & \mathbf{9} & & & & 1 & & 1 \\
 & \mathbf{10} & & & & & 1 &
 \end{array}$$

Identifying recycle sets : the reachability matrix:

If the Boolean sum of the powers of A is formed an element of units results wherever units exists in any power. The resulting matrix is

$$R_n = \sum_{j=1}^n A^j$$

records the connections from i to unit j via some numbers of streams <n as shown in following table

R1		1				
	1		1			
				1		
					1	
						1
				1		
					1	

R2	1	1	1			
	1	1	1	1		
				1	1	
				1	1	1
				1	1	1
				1	1	1

R3	1	1	1	1		
	1	1	1	1	1	
				1	1	1
				1	1	1
				1	1	1
				1	1	1

R	1	1	1	1	1	1
	1	1	1	1	1	1
				1	1	1
				1	1	1
				1	1	1
				1	1	1

Then element r_{ij} in matrix R_n equals 1 if and only if atleast one such connection exists. In the limit as n tends to infinity

$$R_n \rightarrow \omega$$

The reachability matrix records whether any connection exists from unit i to unit j via any number streams. Thus

$$r_{\omega ij} = 1$$

if and only if some connection i to j exists.

Now the transpose of either A or R i. e. A^T R^T has the effect of reversing direction of all the i to j connections since rows become columns and vice versa. In a recycle set there is b definition not only some connection i to j but also some connection j to i . The reachability matrix R and its transpose R^T are superimposed and a unity kept only where unity is in both R and R (infinity)^T

The result is known as intersection is written

$$w \equiv \text{interseciton of } R_{\infty}, R_{\infty}^T$$

and so shown in following table. Now

$$r_{\omega ij} = 1$$

only if i to j in the flow diagramme but

$$r_{\omega ij}^T = r_{\omega ij} = 1$$

only if j to i in the flow diagram. Then

$w_{ij} = 1$ if and only if both r_{ω} and $r_{\omega}^T = 1$ that is $i \leftrightarrow j$

R	1	1	1	1	1	1
	1	1	1	1	1	1
				1	1	1
				1	1	1
				1	1	1
				1	1	1

and its transpose is :

R	1	1				
	1	1				
	1	1				
	1	1	1	1	1	1
	1	1	1	1	1	1
	1	1	1	1	1	1

$w \equiv \text{interseciton of } R_{\infty}, R_{\infty}^T =$

R	1	1				
	1	1				
				1	1	1
				1	1	1
				1	1	1

Recycle sets : (4, 5) , (8, 9, 10)

serial set : 6

This will eliminate any unit which is not in some recycle set because then there will not be a connection from that unit to any other in both directions. But by the definition of a recycle set all members are mutually connected. Thus any nonzero row of matrix reveal a further recycle set and not an inlet or outlet unit is then a serial set between a pair of recycle set and will be directly calculable when the preceding recycle set has been calculated.

Source :

<http://nptel.ac.in/courses/103107096/3>