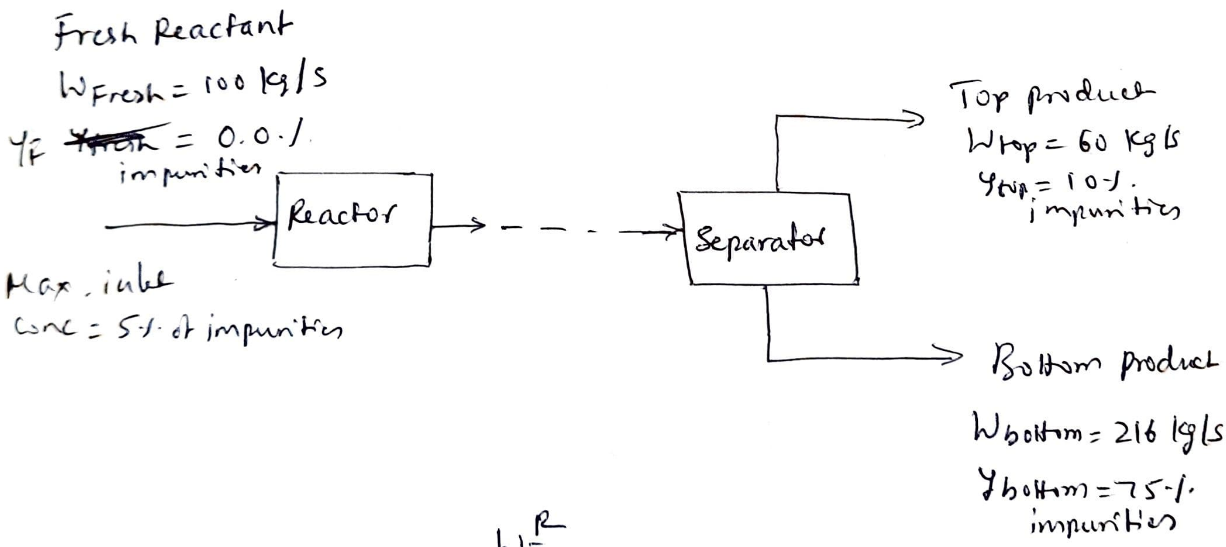
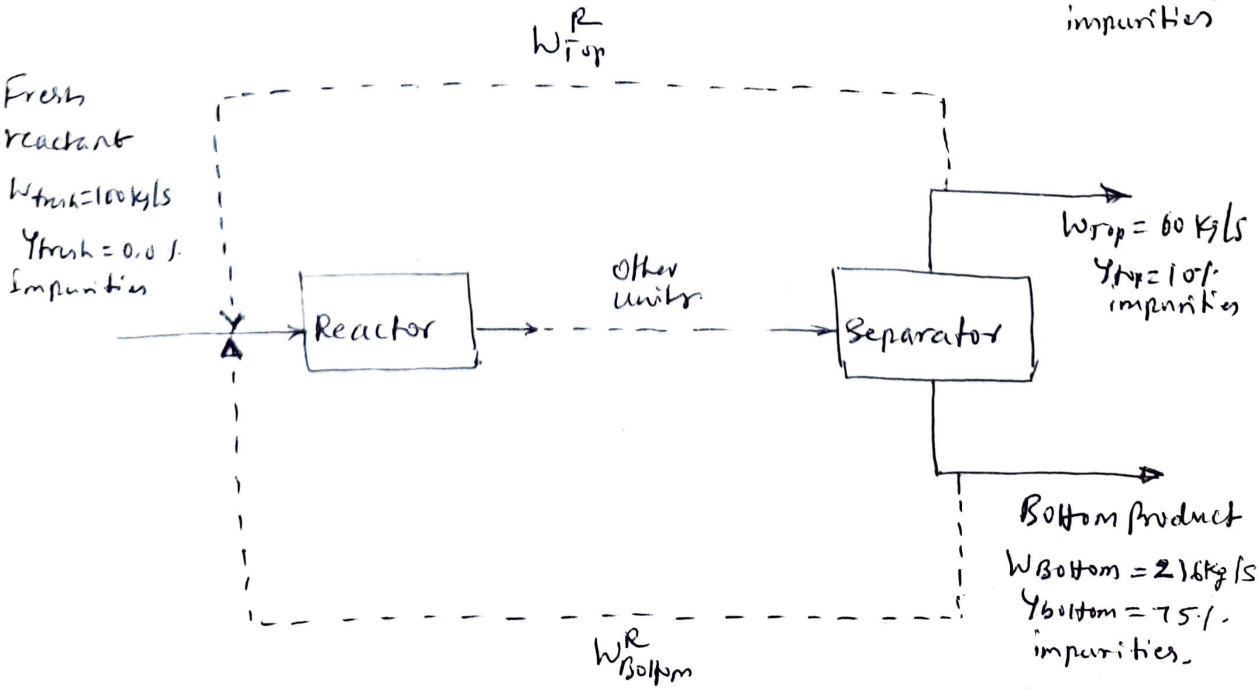
eg. Minimization of Fresh Reactant in a chemical plant.

Consider the chemical process shown in Fig. The reactor consumes 100 kg/s of fresh feed. In order to reduce the consumption of fresh ~~feed~~ reactant, two process sources are considered for recycle to the reactor: the top and bottom products of a separation system. The flow rates of the top product is 60 kg/s and it has 10% (mass basis) of impurities. The bottom product has a flow rate of 216 kg/s and its content of impurities is 75% by mass. Determine the recycle strategies that minimize the usage of the fresh reactant.



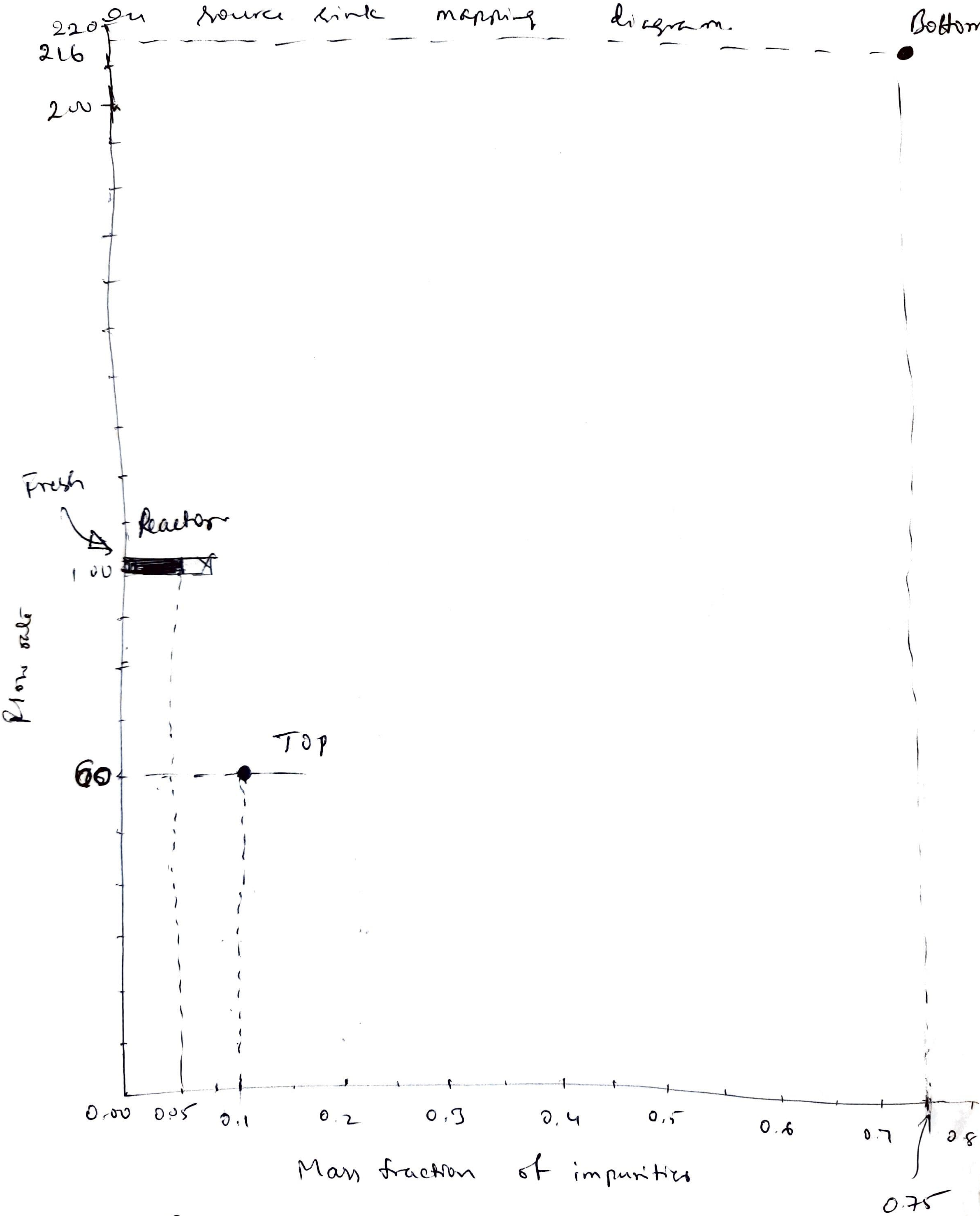


Recycle alternative

Soln:

There are two ~~candidate~~ recycle alternatives as shown in Fig. (W^{R}_{Top} and W^{R}_{Bottom})

To determine recycle strategies, represent source & sink on source sink mapping diagram.



Source sink mapping Diagram

Since the top product has the shortest fresh arm, we start with top product.

$$\frac{\text{Fresh flow rate need in sink}}{\text{Total flow rate fed to sink}} = \frac{y_a - z_{feed\ to\ sink}}{y_a - y_{Fr}}$$

$$\frac{\text{fresh flow rate need in sink}}{100} = \frac{0.1 - 0.05}{0.1 - 0.00}$$

Fresh flow rate need in sink = 50 kg/s

Flow rate of the top product recycled (W^R_{TOP}) to the reactor

By material balance,

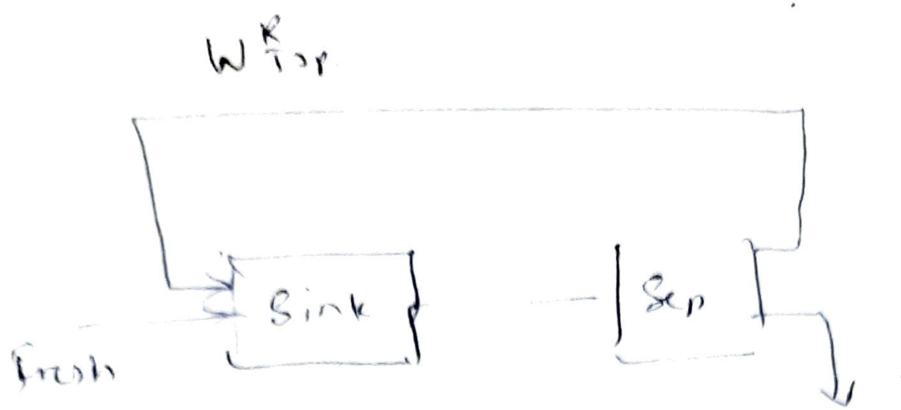
Fresh + W_R^{TOP} = 100

W_R^{TOP} = 100 - 50
= 50 kg/s.

It is worth to note that since not all the top product has been recycled, there is no need ~~to~~ to consider the bottom product for recycle (W_R^{Bottom} = 0.0 kg/s). This is attributed to source prioritization rule which indicates that the source with shortest fresh arm should be completely used before the next-to-shortest fresh armed source be considered.

Alternate

The same result can be obtained from a component material balance including recycles from the top stream and the fresh reactant.



$$Fresh \times 0.0 + W^R_{Top} \times 0.1 = 100 \times 0.05$$

$$W^R_{Top} = \frac{100 \times 0.05}{0.1} = 50 \text{ kg/s.}$$

$W^R_{Top} = 50$ kg/s and Fresh $= 50$ kg/s

$\therefore$ 50% reduction is accomplished in

Nitrogen Recycle in a Magnetic Tape plant.

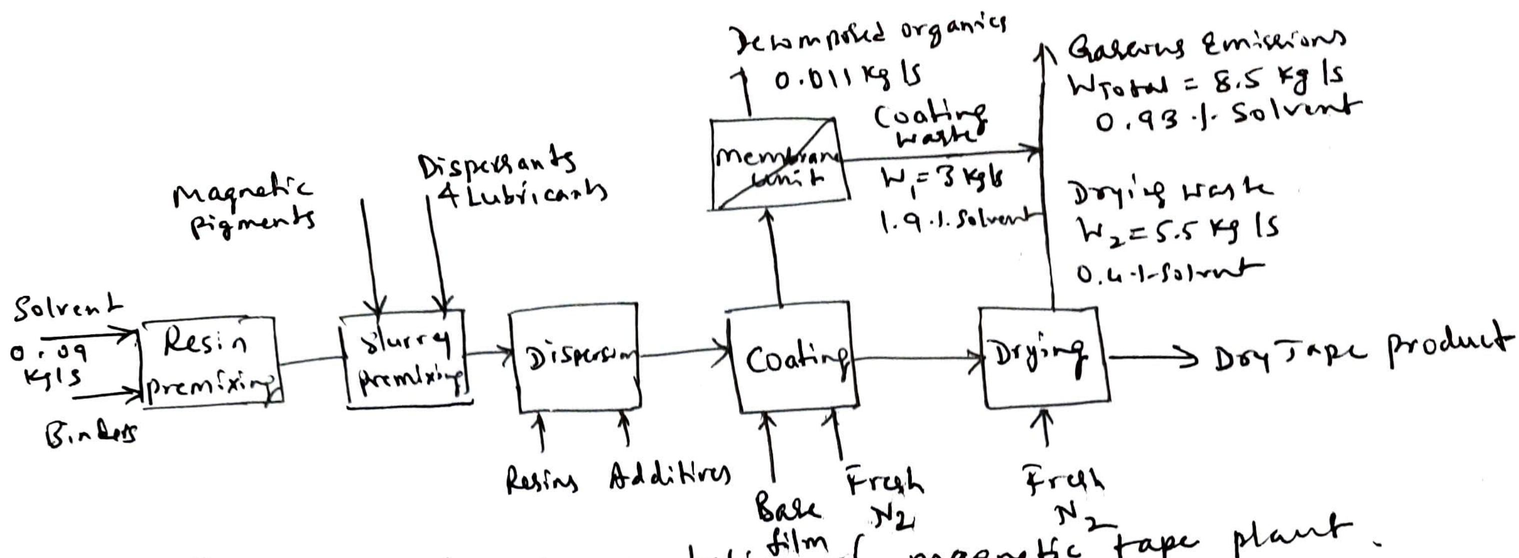


Fig. schematic representation of magnetic tape plant.

Consider magnetic tape manufacturing unit shown in fig. Coating ingredients are dissolved in 0.09 kg/s of organic solvent and mixed to form slurry. The slurry is suspended with resin binders and special additives. Coating slurry is deposited on a base film using N_2 gas which induce evaporation rate of solvent. In the coating chamber 0.011 kg/s of solvent are decomposed into organic species and are separated from exhaust gas using membrane unit. The coated film is passed to a dryer where N_2 gas is used to evaporate remaining solvent. The exhaust gas leaving the dryer and membrane unit are mixed and disposed off.

It is desired to undertake direct recycle initiative to use solvent laden nitrogen (waste gases) in place of fresh N_2. The following constraints on the gaseous feed to these two units should be observed

Coating

$$3.0 \le \text{flowrate of gaseous feed (kg/s)} \le 3.2$$
$$0.0 \le \text{wt.\% of solvent} \le 0.2$$

Dryer

$$5.5 \le \text{flow rate of gaseous feed (kg/s)} \le 6.0$$
$$0.0 \le \text{wt.\% of solvent} \le 0.1$$

Using segregation, mixing and direct recycle, what is the minimum consumption of N_2 gas that should be used in the process? What are the strategies leading to the target?

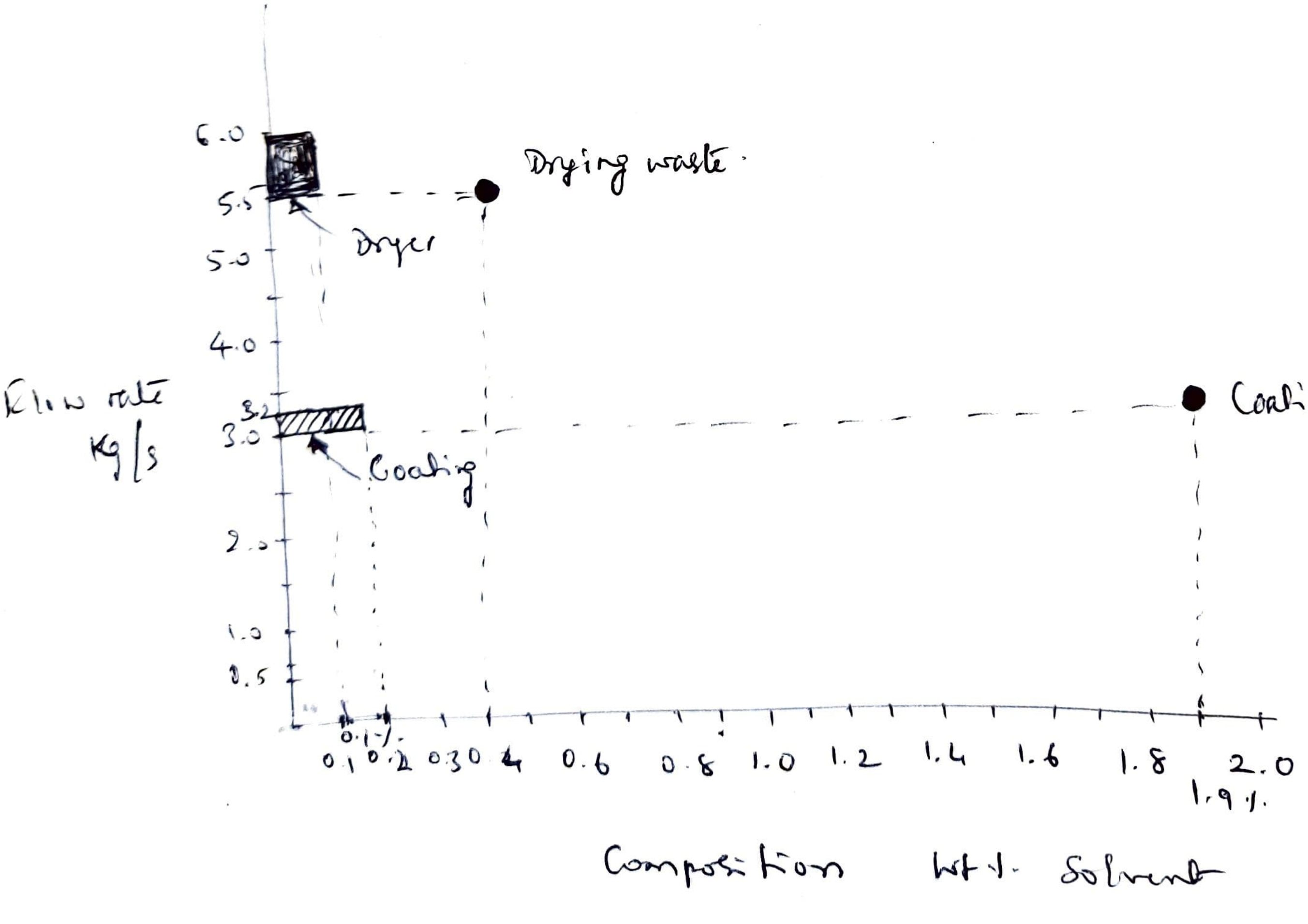
Magnetic Tape plant.

Solution:

(1) Determine the sources and sinks to be included in the analysis.

The exhaust gas emission is segregated to its two sources: Coating waste and drying waste. We will consider the recycle of segregated sources and not the mixed source. Select coating and drying chambers as sink since they use fresh nitrogen

The source sink diagram is shown in Fig.



Source sink mapping diagram for magnetic tape plant.

Coating unit

For the coating unit, the shortest fresh arm of the process sources is that of drying waste. As can be seen from the figure, the flow rate and composition of the drying waste exceed the maximum allowable for coating. (Excess flow rate is reduced by recycling portion of drying waste and the rest is by passed; High composition of the solvent is reduced by using interception device)

Here, our focus is on direct recycle where no new equipment is to be added, we must consider mixing a portion of the drying waste with fresh nitrogen, thereby adjusting the composition of the mixture lie inside the coating box

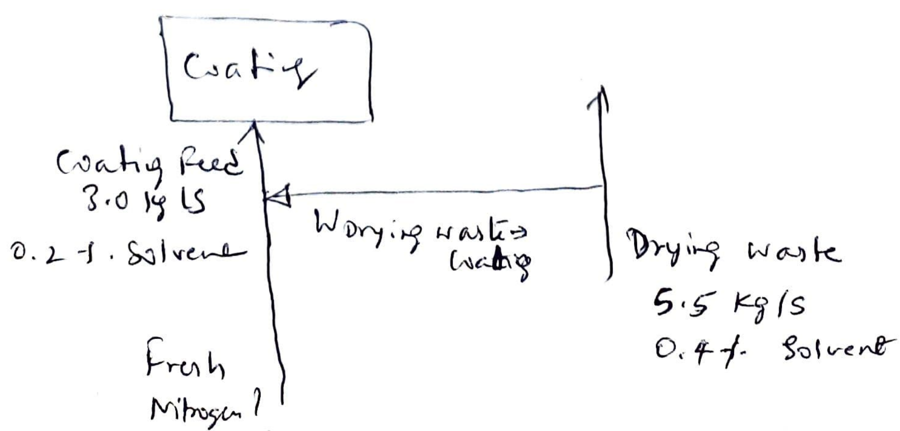
According to sink composition rule, in order to reduce fresh nitrogen, the composition of the mixture entering the coating should be maximum.

$\therefore$ Composition of the mixture $= 0.2$ wt% $= 0.002$

Flow rate of feed to the coating unit $= 3.0$ kg/s

(3.0 to 3.2 kg/s, select 3.0 to reduce N_2)

Let flow rate of drying waste that is to be recycled to coating unit as $W_{\text{drying waste} \to \text{coating}}$



Lever arm equation

$$\frac{\text{Fresh flowrate used in sink}}{\text{Total flow rate fed to sink}} = \frac{y_a - z_{\text{feed to sink}}}{y_a - y_r}$$

$$\frac{\text{Fresh } N_2 \text{ in coating}}{3.0} = \frac{0.004 - 0.002}{0.004 - 0.00}$$

Fresh nitrogen used $= 3.0 - 1.5 = 1.5$ kg/s

$W_{\text{Drying waste}} \rightarrow \text{coating} = 3.0 - 1.5 = 1.5$ kg/s

Since drying waste has not been fully utilized, its remaining flow rate should be considered for recycle to the drying unit as it provides the shorter arm

lever arm

$$\frac{\text{Fresh flow rate used in sink}}{\text{Total flow rate fed to sink}} = \frac{y_a - z_{\text{feed to sink}}}{y_a - y_r}$$

$$\frac{\text{Fresh } N_2 \text{ used in drying}}{5.5} = \frac{0.004 - 0.001}{0.004 - 0.0}$$

Fresh N_2 used in drying unit $= 4.125$ kg/s.

Hence $W_{\text{drying waste}} \rightarrow \text{Drying} = 5.5 - 4.125 = 1.375$ kg/s

Min Fresh N_2 consumption in coating and drying units

$= 1.5 + 4.125 = 5.625$ kg/s

Compared to original fresh N_2 (8.5 kg/s), direct recycle saves 34% of fresh N_2 purchase