ABE 201
Biological Thermodynamics 1

Module 4

Degree of Freedom Analysis

and

Multiple Unit Operations

Summary

- Defining Systems in Complex Processes
  - Boundaries must be contiguous
  - Boundaries define what's in and what's out!
  - Careful selection of system boundaries can be used to solve complex problems

- Degree of Freedom Analysis
  - Determine if a unique solution is possible for the system as you have defined it.
  - The number of equations must equal or exceed the number of unknown variables

Tactical Garbage to Energy Reactor (TGER)

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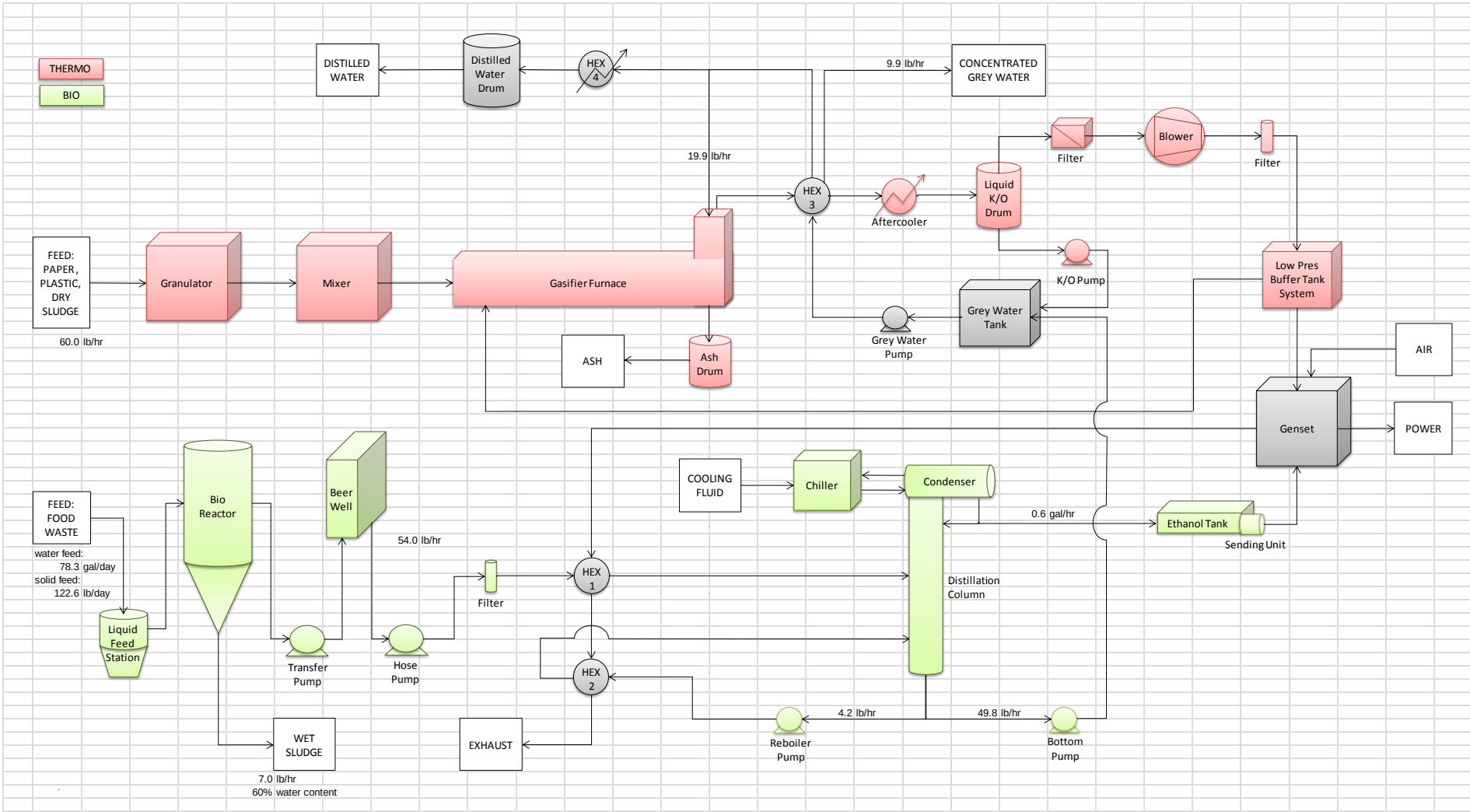
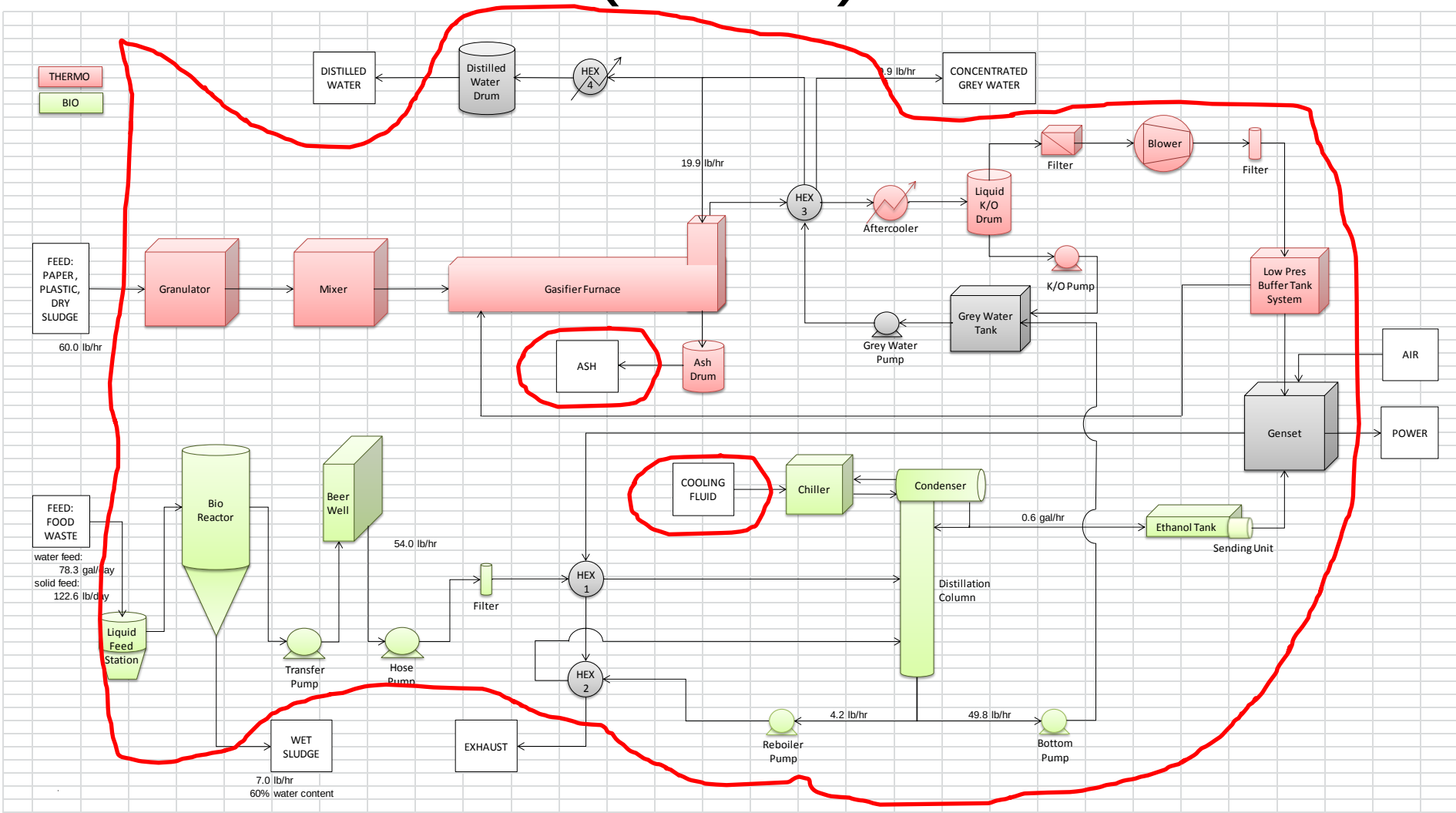


TGER

- How many unit operations are shown in the process flow diagram? 32

- How many systems can be defined?

Tactical Garbage to Energy Reactor (TGER)



Pharmaceutical Recovery

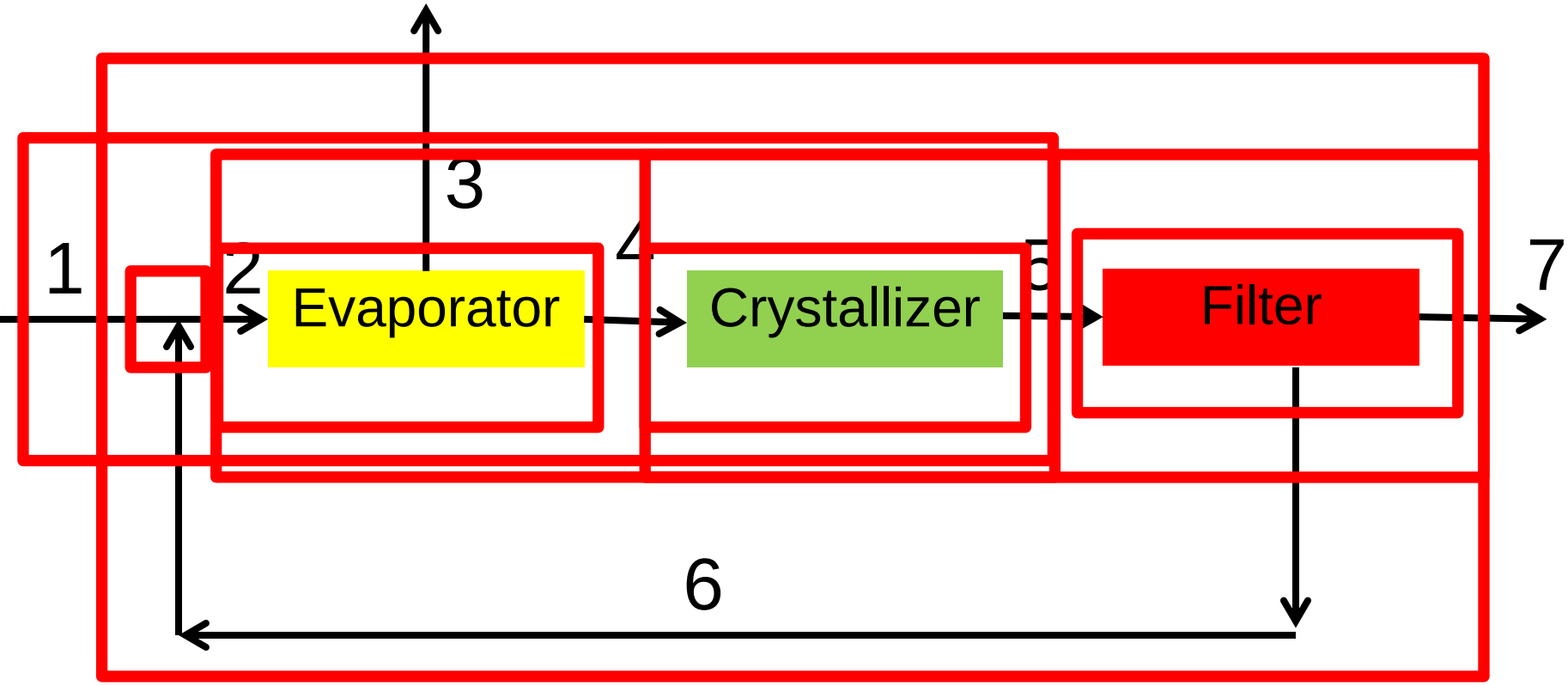
After synthesis, a pharmaceutical is recovered from solvent at steady state. The starting material (feed) is made at 4521 kg/h and contains 3% (w/w) drug and the remainder is solvent. It is mixed with recycled solvent and unrecovered drug before processing.

In the first processing step, 50% of the solvent is removed by evaporation, leaving the drug behind and concentrated in the remaining solvent.

In the second step, the mixture (2573 kg/h) is cooled causing 95% of the drug entering the second step to crystalize and precipitate from solution.

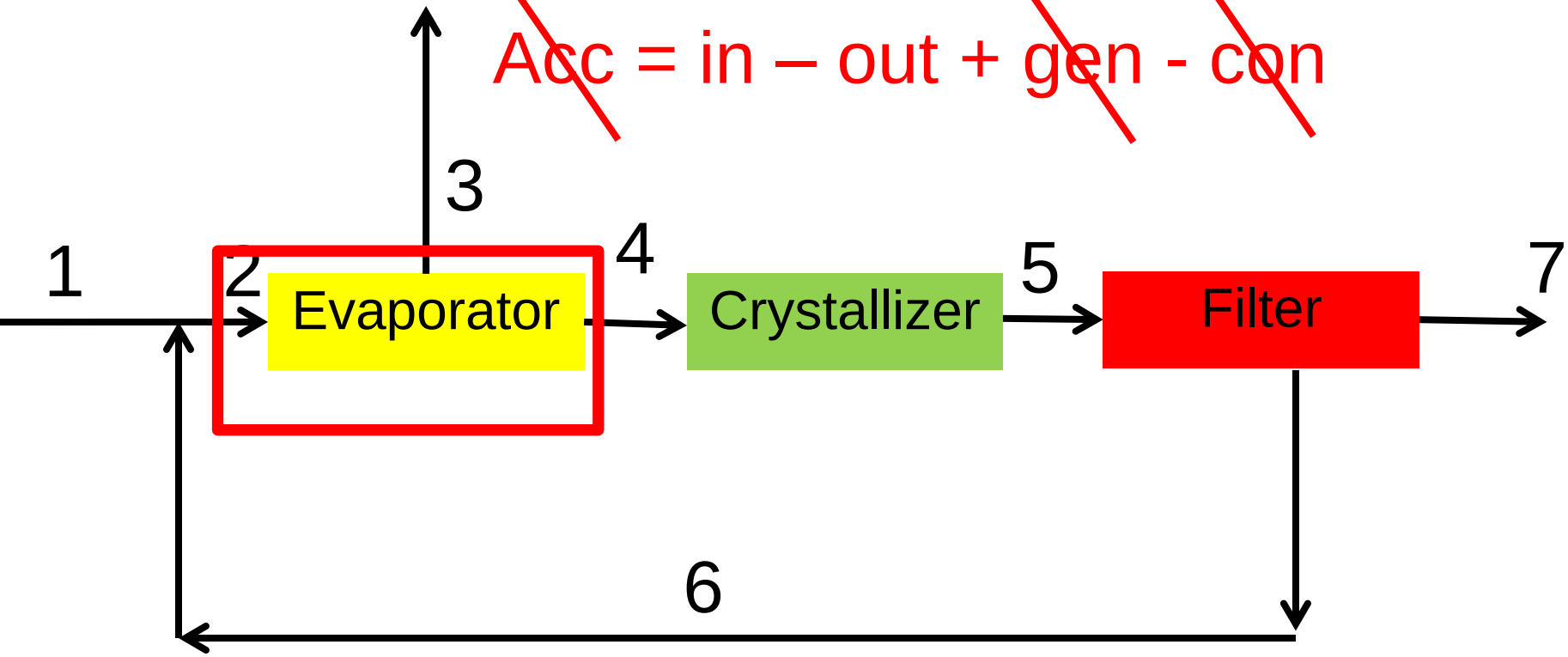
In the third step, the crystalized drug is filtered out. The filter cake is 75% drug and 25% solvent. The remaining solvent with un-crystalized drug is recycled where it is blended with the feed and fed to the evaporator.

What is the mass flow rate of the recycled solvent and drug?



	1	2	3	4	5	6	7
m (kg/h)	4521	m_2	m_3	2573	m_5	m_6	m_7
x_d	0.03	x_{2d}	0	x_{4d}	x_{5d}	x_{6d}	0.75
x_s	0.97	x_{2s}	1	x_{4s}	x_{5s}	x_{6s}	0.25

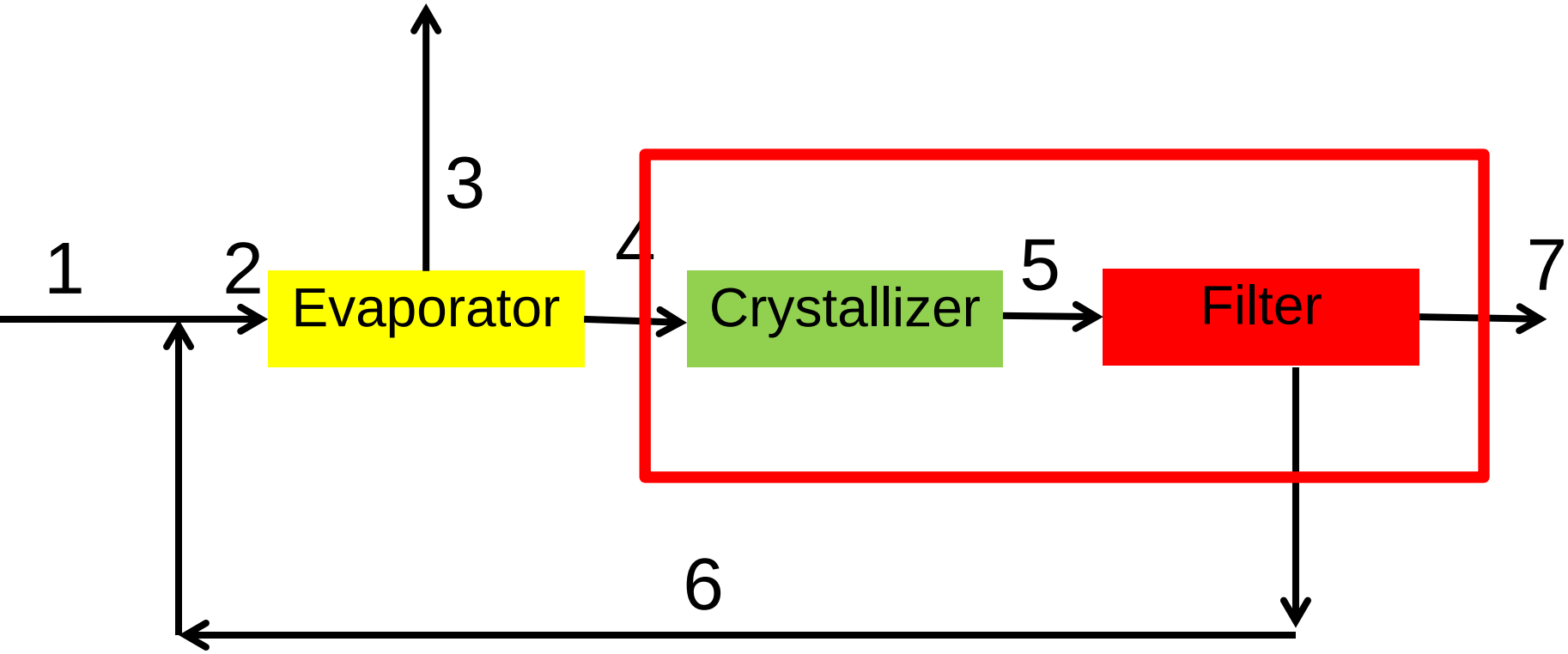
Acc = in – out + gen - con



$m_3 = (0.50)*(x_{2s}*m_2)$

	1	2	3	4	5	6	7
m (kg/h)	4521	m_2	m_3	2573	m_5	m_6	m_7
x_d	0.03	x_{2d}	0	x_{4d}	x_{5d}	x_{6d}	0.75
x_s	0.97	x_{2s}	1	x_{4s}	x_{5s}	x_{6s}	0.25

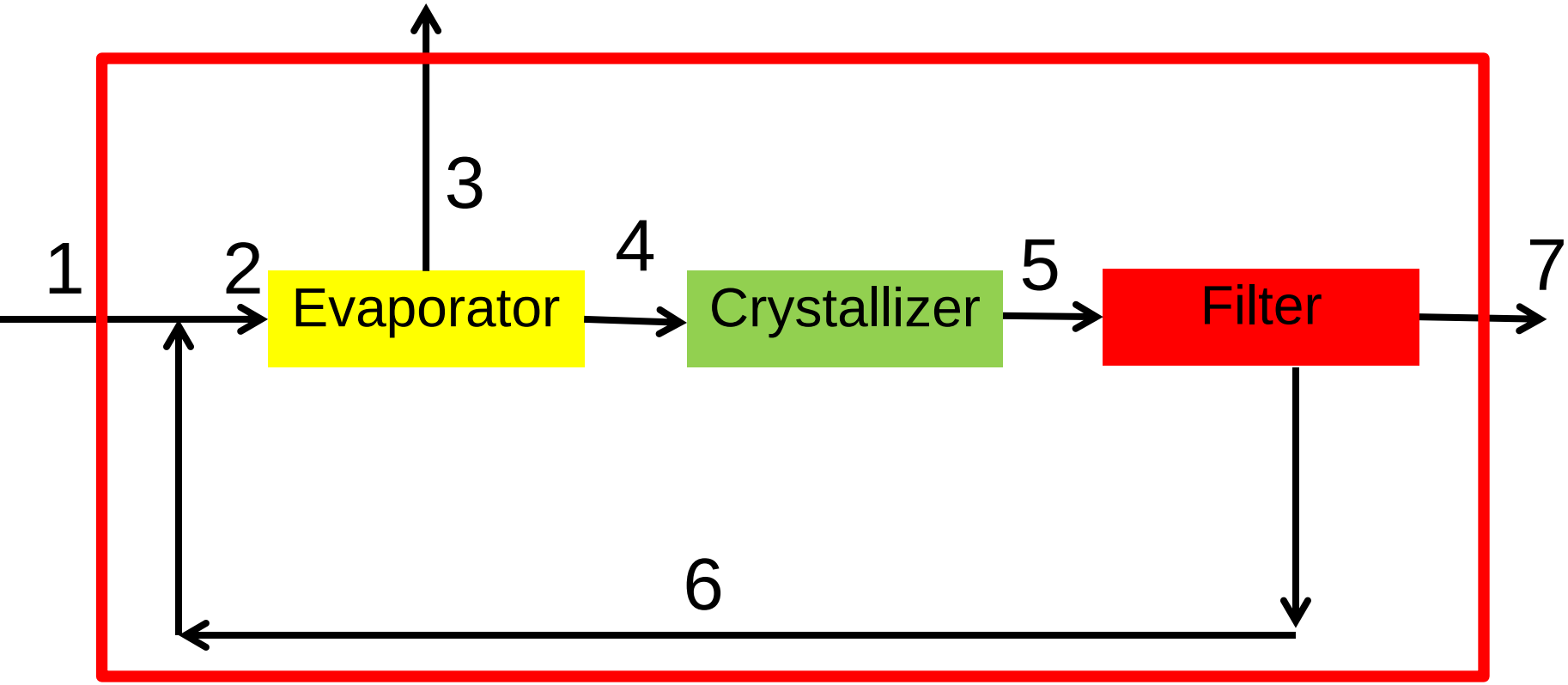
DOF = V – B – P – C = 6 – 2 – 0 – 3 = 1



$$x_{7d} * m_7 = (0.95) * (x_{4d} * m_4)$$

	1	2	3	4	5	6	7
m (kg/h)	4521	m_2	m_3	2573	m_5	m_6	m_7
x_d	0.03	x_{2d}	0	x_{4d}	x_{5d}	x_{6d}	0.75
x_s	0.97	x_{2s}	1	x_{4s}	x_{5s}	x_{6s}	0.25

$$DOF = V - B - P - C = 6 - 2 - 0 - 3 = 1$$



	1	2	3	4	5	6	7
m (kg/h)	4521	m_2	m_3	2573	m_5	m_6	m_7
x_d	0.03	x_{2d}	0	x_{4d}	x_{5d}	x_{6d}	0.75
x_s	0.97	x_{2s}	1	x_{4s}	x_{5s}	x_{6s}	0.25

$$DOF = V - B - P - C = 2 - 2 - 0 - 0 = 0$$

$$0 = \text{In} - \text{Out}$$

Total Mass

$$0 = (m_1) - (m_3 + m_7)$$

$$0 = 4521 - (m_3 + m_7)$$

$m_3 = 4340.6$ kg/h

Drug Mass

$$0 = (x_{1d} * m_1) - (x_{3d} * m_3 + x_{7d} * m_7)$$

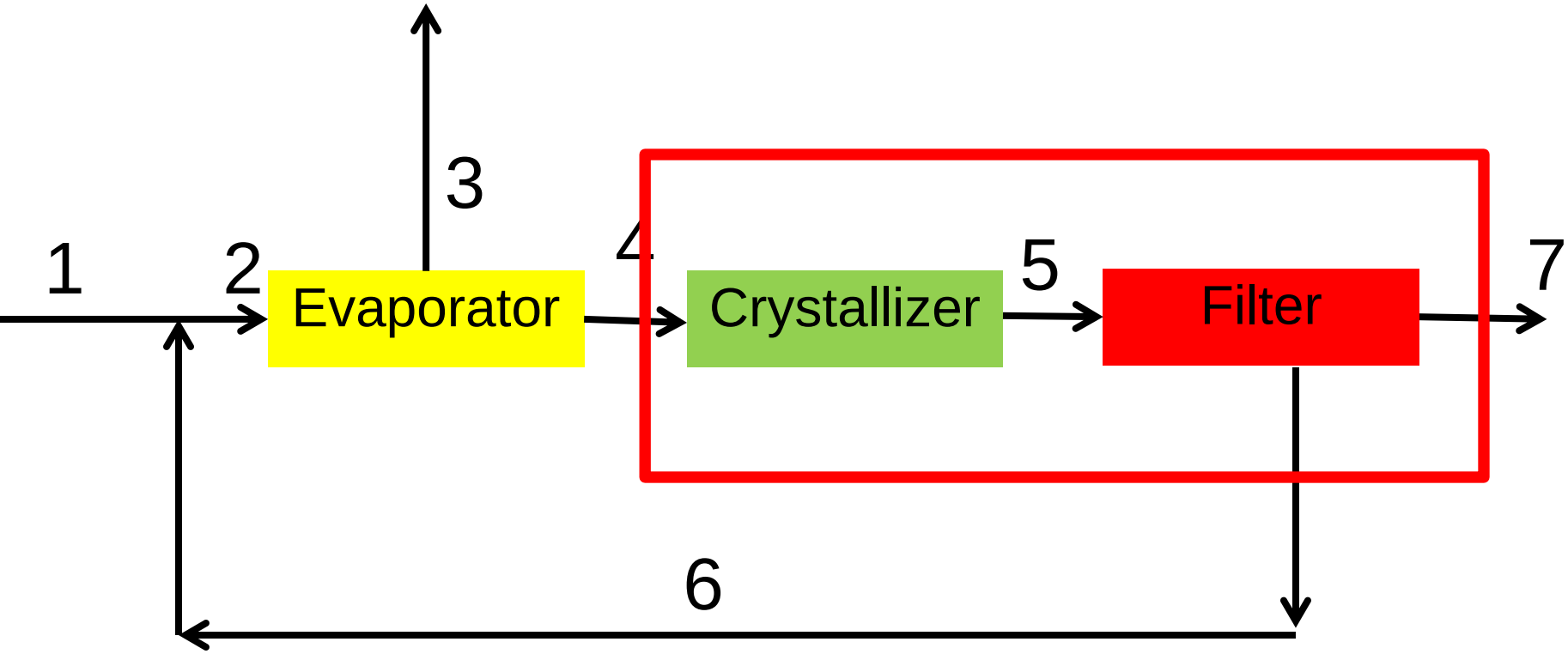
$$0 = (0.03 * 4521) - (0 + 0.75 * m_7)$$

$m_7 = 180.4$ kg/h

Solvent Mass

$$0 = (x_{1s} * m_1) - (x_{3s} * m_3 + x_{7s} * m_7)$$

$$0 = (0.97 * 4521) - (m_3 + 0.25 * m_7)$$



$$x_{7d} * m_7 = (0.95) * (x_{4d} * m_4)$$

	1	2	3	4	5	6	7
m (kg/h)	4521	m_2	4340.6	2573	m_5	m_6	180.4
x_d	0.03	x_{2d}	0	x_{4d}	x_{5d}	x_{6d}	0.75
x_s	0.97	x_{2s}	1	x_{4s}	x_{5s}	x_{6s}	0.25

$$DOF = V - B - P - C = 5 - 2 - 0 - 3 = 0$$

$$0 = \text{In} - \text{Out}$$

Total Mass

$$0 = (m_4) - (m_7 + m_6)$$

$$0 = 2573 - (180.4 + m_6)$$

$$m_6 = 2392.6 \text{ kg/h}$$

Example

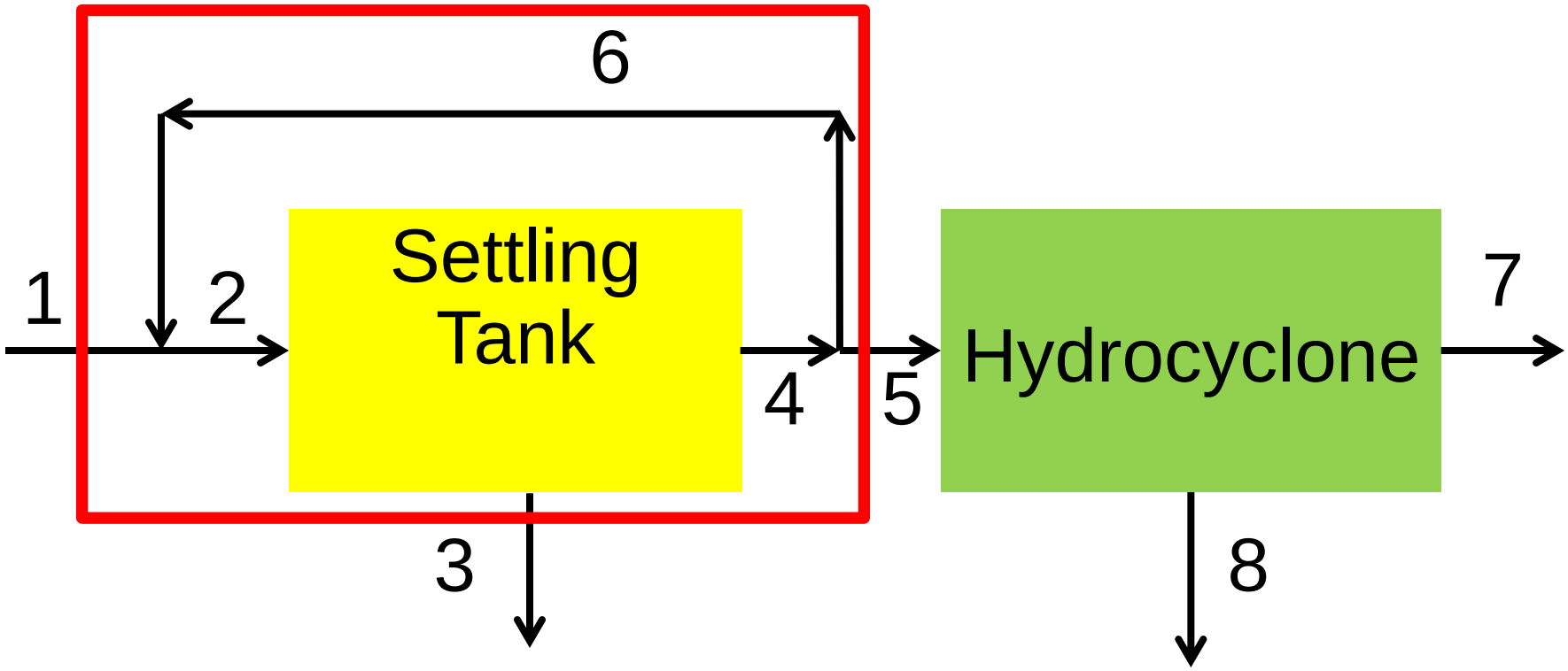
Waste water treatment slurry (50.% solids) is processed at a rate of 100. kg/hr.

The slurry is mixed with a recycle stream and goes into a settling tank where some of the solids settle out to form a sludge (90.% solids) which is removed from the bottom by a conveyor.

The upper layer (40.% solids) is pumped from the far side of the settling tank at 125 kg/hr. A portion is recycled to dilute the incoming waste while the remainder is pumped through a hydrocyclone that produces a heavy cake (98% solids) and a light effluent (1.0% solids). Assume steady-state operation.

Questions

- What percent of effluent is being recycled?
- What is the flow rate of clarified effluent from the hydrocyclone?
- What is the total flow rate of high solids streams (sludge + heavy cake)?



	1	2	3	4	5	6	7	8
m	100	m_2	m_3	125	m_5	m_6	m_7	m_8
x_s	0.5	x_{2s}	0.9	0.4	0.4	0.4	0.01	0.98
x_w	0.5	x_{2w}	0.1	0.6	0.6	0.6	0.99	0.02

$$DOF = V - B - P - C = 2 - 2 - 0 - 0 = 0$$

$$\text{Acc} = \text{In} - \text{Out} + \text{Gen} - \text{Con}$$

Total Mass

$$0 = (m_1) - (m_3 + m_5)$$

$$0 = 100 - (m_3 + m_5)$$

$m_3 = 20$ kg/h

$m_5 = 80$ kg/h

Solids Mass

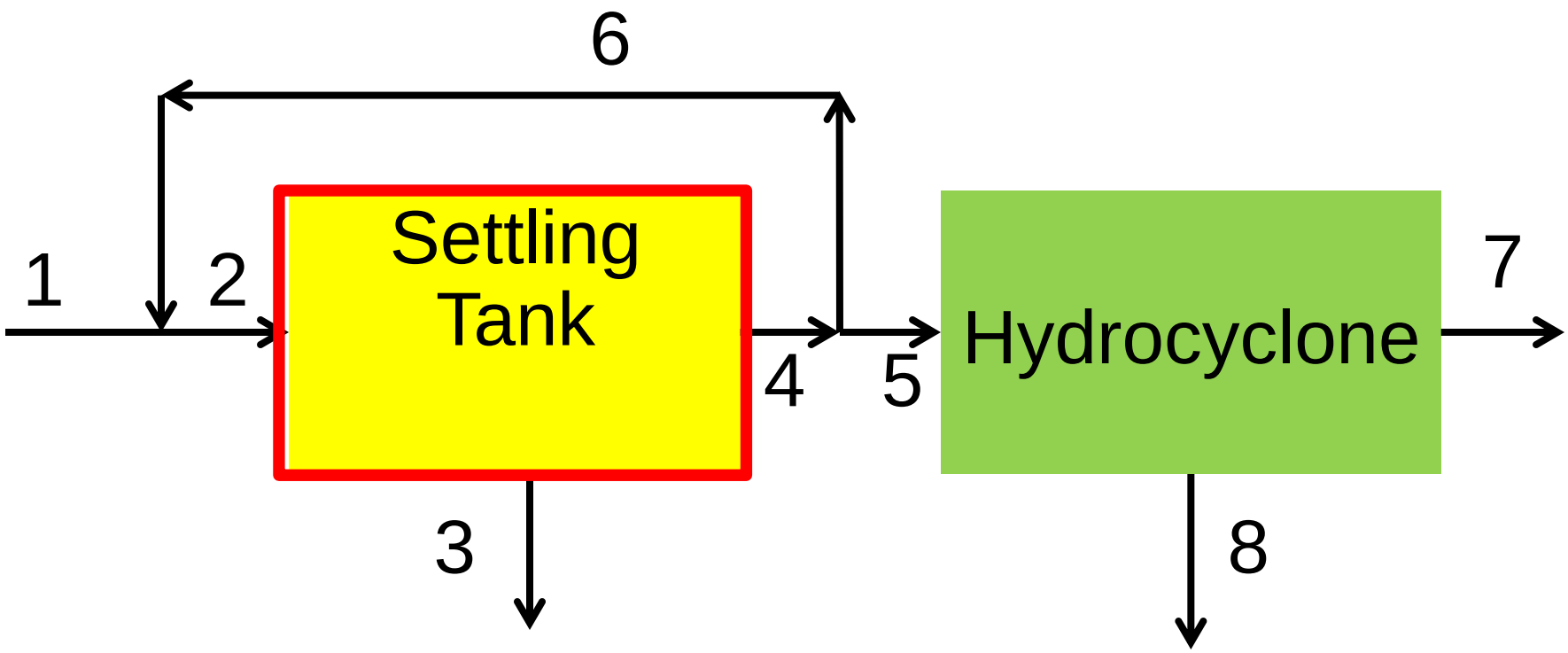
$$0 = (x_{1s} * m_1) - (x_{3s} * m_3 + x_{5s} * m5)$$

$$0 = (50) - (0.9 * m_3 + 0.4 * m5)$$

Water Mass

$$0 = (x_{1w} * m_1) - (x_{3w} * m_3 + x_{5w} * m5)$$

$$0 = (50) - (0.1 * m_3 + 0.6 * m5)$$



	1	2	3	4	5	6	7	8
m	100	m_2	20	125	80	m_6	m_7	m_8
x_s	0.5	x_{2s}	0.9	0.4	0.4	0.4	0.01	0.98
x_w	0.5	x_{2w}	0.1	0.6	0.6	0.6	0.99	0.02

DOF = V – B – P – C = 3 – 2 – 0 – 1 = 0

$$\text{Acc} = \text{In} - \text{Out} + \text{Gen} - \text{Con}$$

Total Mass

$$0 = (m_2) - (m_3 + m_4)$$

$$m2 = 145 \text{ kg/h}$$

$$0 = m_2 - (20 + 125)$$

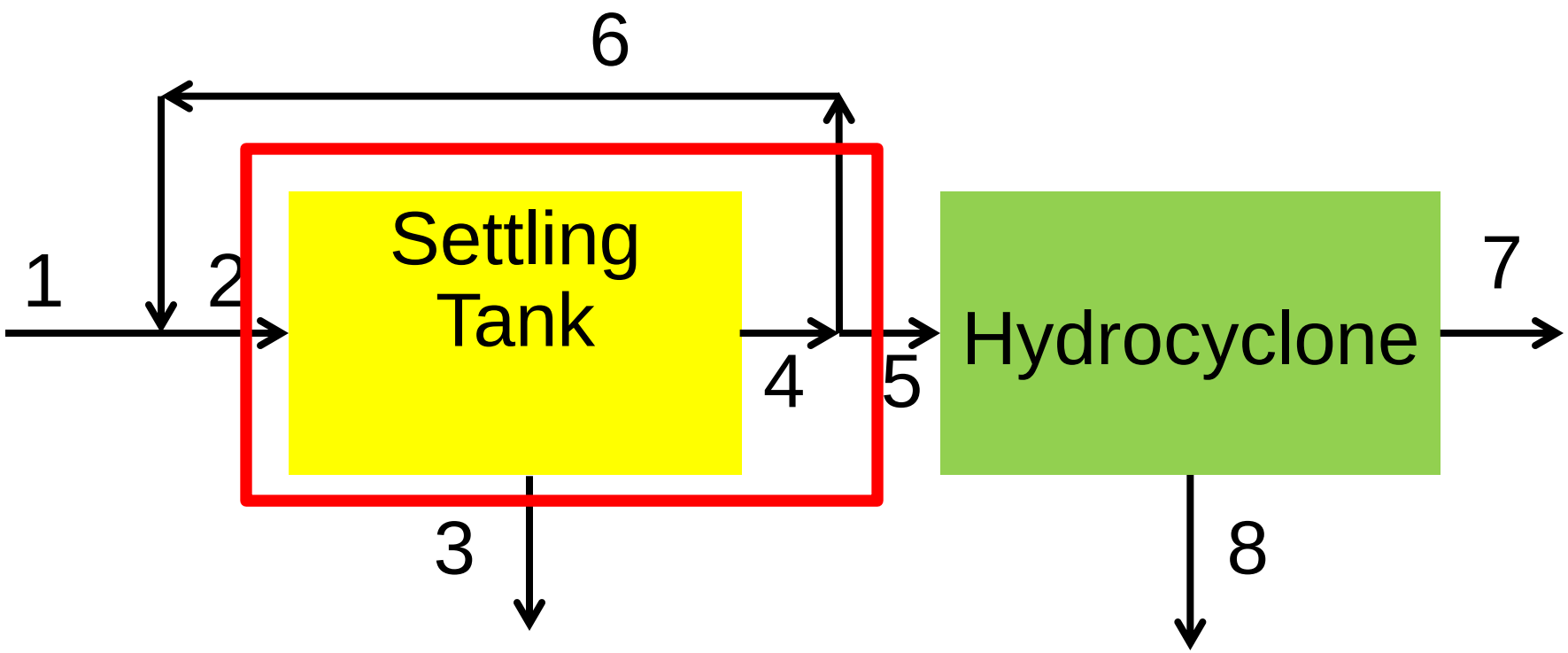
Solids Mass

$$0 = (x_{2s} * m_2) - (x_{3s} * m_3 + x_{4s} * m_4)$$

$$0 = x_{2s}(145) - (0.9 * 20 + 0.4 * 125)$$

$$x_{2s} = 0.469$$

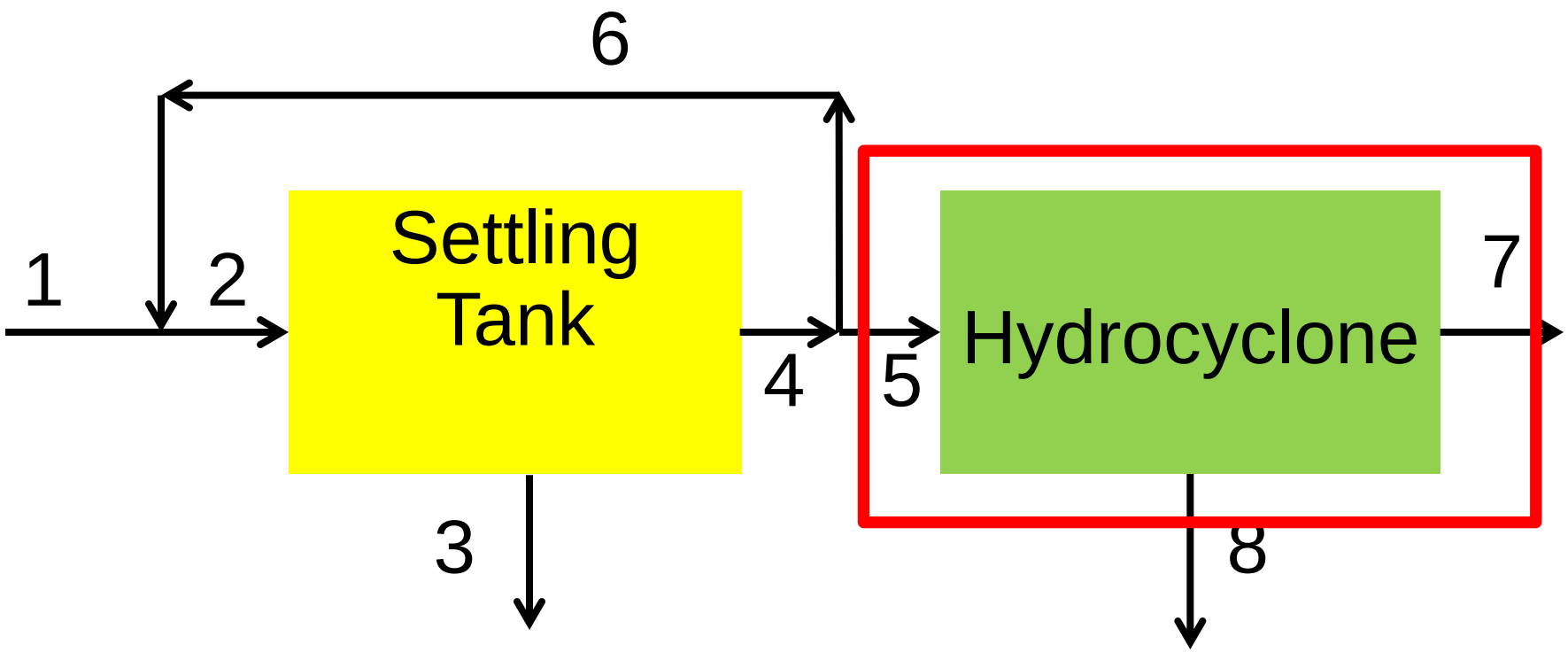
$$x_{2w} = 1 - x_{2s} = 0.531$$



$M_6 = 145-20-80= 45$

	1	2	3	4	5	6	7	8
m	100	145	20	125	80	m_6	m_7	m_8
x_s	0.5	0.469	0.9	0.4	0.4	0.4	0.01	0.98
x_w	0.5	0.531	0.1	0.6	0.6	0.6	0.99	0.02

% recycled = $M_6 / M_4 = 45/125 = 36\%$



	1	2	3	4	5	6	7	8
m	100	145	20	125	80	45	m_7	m_8
x_s	0.5	0.469	0.9	0.4	0.4	0.4	0.01	0.98
x_w	0.5	0.531	0.1	0.6	0.6	0.6	0.99	0.02

$$\text{Acc} = \text{In} - \text{Out} + \text{Gen} - \text{Con}$$

Total Mass

$$0 = (m_5) - (m_7 + m_8)$$

$$0 = 80 - (m_7 + m_8)$$

$m_7 = 47.8$ kg/h

$m_8 = 32.2$ kg/h

Total sludge =

$m_3 + m_8 = 20.0 + 32.2$ **= 52.2kg/h**

Solids Mass

$$0 = (x_{5s}*m_5) - (x_{7s}*m_7 + x_{8s}*m_8)$$

$$0 = (0.4*80) - (0.01*m_7 + 0.98*m_8)$$

Water Mass

$$0 = (x_{1w}*m_1) - (x_{7w}*m_7 + x_{8w}*m_8)$$

$$0 = (0.6*80) - (0.99*m_7 + 0.02*m_8)$$