EngrD 2190 – Lecture 24

Concept: Graphical Mass Balances – Operating Lines

Context: Multi-Stage Countercurrent Absorbers

Defining Question: What is an operating line?

Bring a Straightedge or Ruler to Lecture 25.

Prelim 2

- Prelim 2: TOMORROW 10/30, 7:30-9:30 p.m., 245 and 128 Olin Hall

  Mathematical Modeling:

  energy balances and process economics

  mass balances on spreadsheets

  Graphical Modeling:

  graphical energy balances: energy lines.

  flash drums: T-(x,y) and P-(x,y) phase maps.

  Design using single-stage units (L-V, L-L, and S-L separators) with T-(x,y) and P-(x,y) phase maps.

  Open notes and open exercise solutions.

  Bring a calculator and a ruler. Graphing calculators are allowed.

- Practice exercises: 3.74, 3.76, and 3.79 – energy balances
  3.96, 3.97, and 3.99 – process economics
  4.3, 4.7, and 4.88 – graphical energy balances
  4.89 and 4.90 – design with flash drums

  Solutions are posted.

Prelim 2

Grading Rubric for Formal Graphical Model.

Validity of graphical model **16 points**

translated process and mathematical equations to points and lines.

(list of 8 specific features of the graphical model)

Style of graphical model. **4 points**

"*Everything drawn on the phase map has an explicit source*."

Straight and horizontal lines for mixing lines

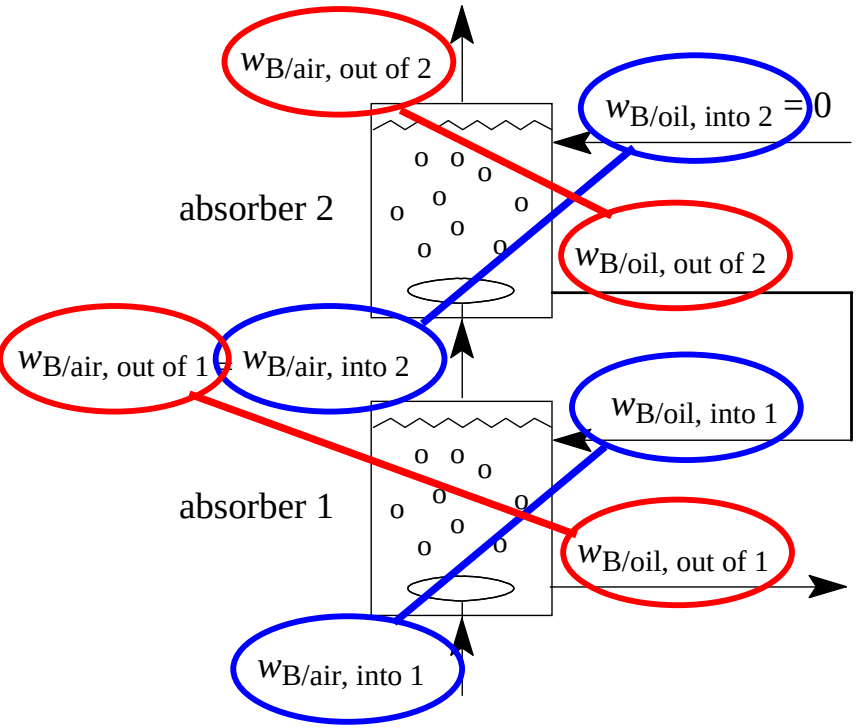
Straight and vertical lines to read numbers on axes.

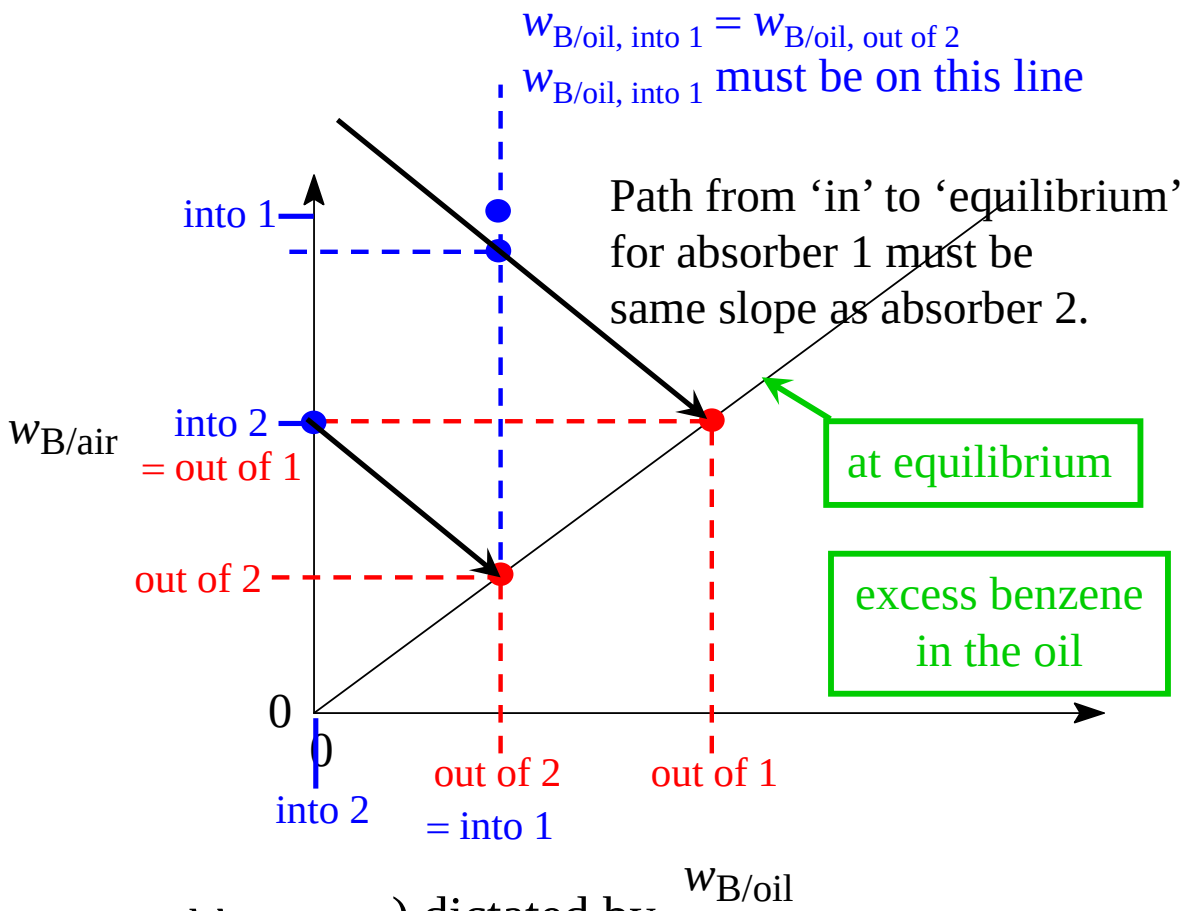
All streams labeled.

Answer has proper significant figures and correct units.

Constants such as C_P and $\Delta H_{melting}$ and $\Delta H_{evaporation}$ should not appear in a graphical modeling analysis.

Graphical Analysis of a *Better* Two-Stage Absorber: Counter-Current Flow





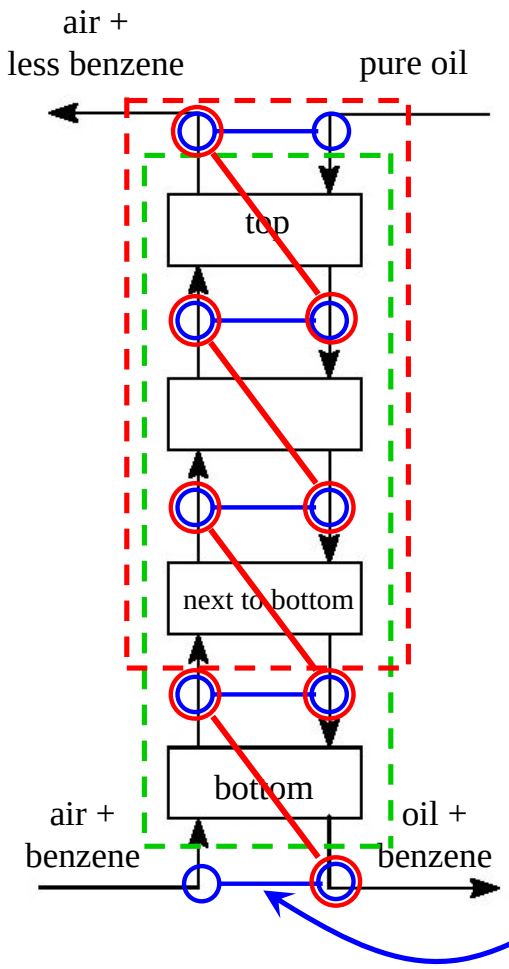
Point for $(x,y) = (w_{B/oil,\ into\ 1}, w_{B/air,\ into\ 1})$ dictated by intersection does not agree with $w_{B/air,\ into\ 1}$.

Must iterate until intersection agrees with $w_{B/air,\ into\ 1}$.

Iteration is tedious for a two-stage absorber. Iteration is unthinkable for a 10-stage absorber.

There must be a better way …

Graphical Analysis of Multi-Stage Counter-Current Absorbers: A Better Graphical Model.



parameters:

1. $w_{B/air,\ in}$
2. $w_{B/air,\ out}$ — given
3. $w_{B/oil,\ in} = 0$
4. $w_{B/oil,\ out}$ — unknown
5. F_{air}
6. F_{oil} — given

Mass Balance: rate of benzene in = rate of benzene out

(See eqns 4.29 to 4.35, p. 274.)

$$w_{B/air,\ into\ bottom} = \left(\frac{F_{oil}}{F_{air}}\right) w_{B/oil,\ out\ of\ bottom} + w_{B/air,\ out\ of\ top}$$

$$y = (\text{slope}) \times x + y\ \text{intercept}$$

Adjacent (x,y) pair lies on a line with slope F_{oil}/F_{air}.

rate of benzene in = rate of benzene out

$$w_{B/air,\ into\ next\ to\ bottom} = \left(\frac{F_{oil}}{F_{air}}\right) w_{B/oil,\ out\ of\ next\ to\ bottom} + w_{B/air,\ out\ of\ top}$$

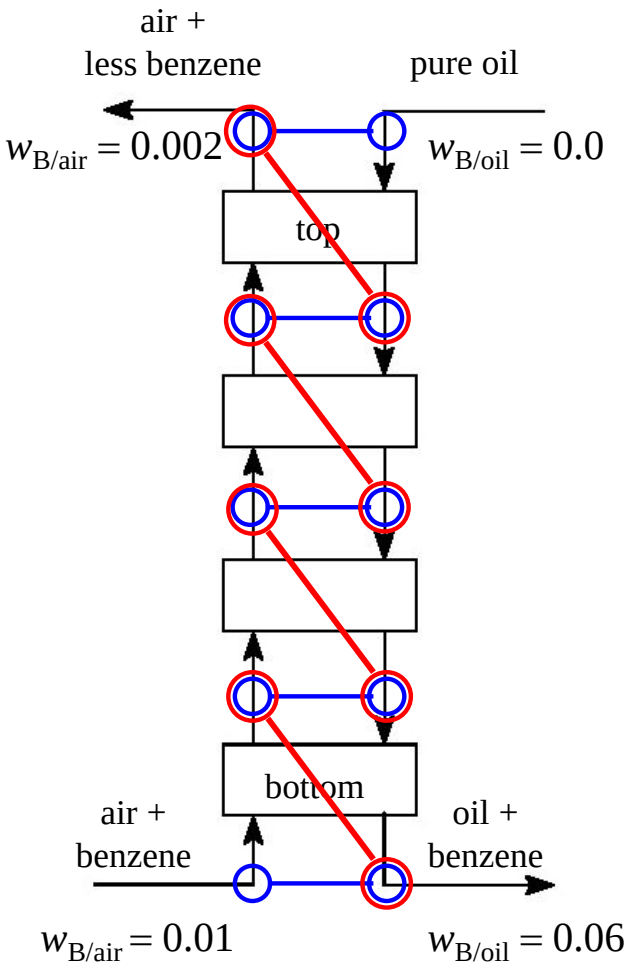
All adjacent (x,y) pairs lie on a line with slope F_{oil}/F_{air}.

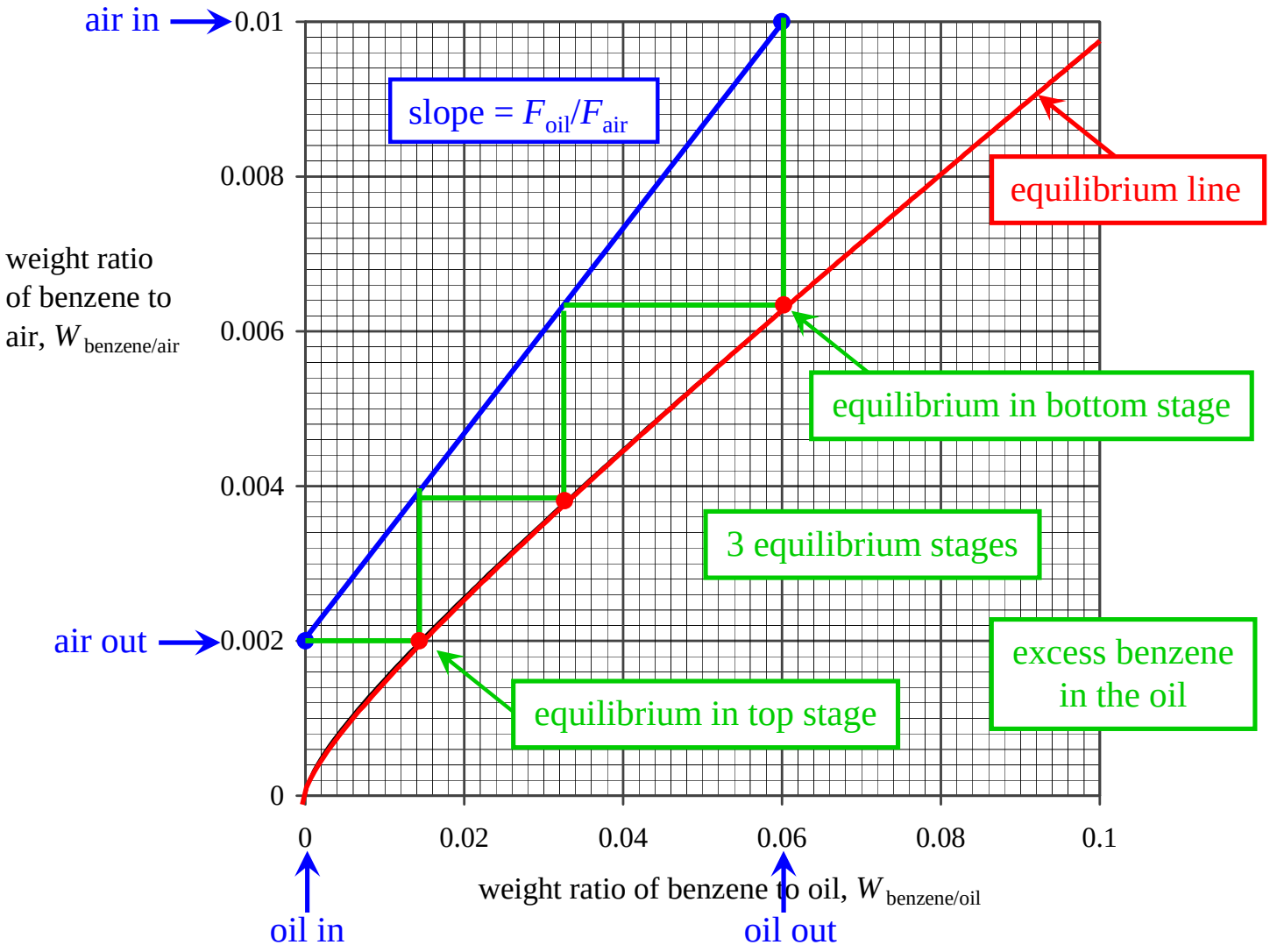
This line is the ***Operating Line***.

All (x,y) pairs leaving an equilibrium stage lie on the equilibrium line.

Graphical Analysis of Multi-Stage Counter-Current Absorbers: Example 1

All compositions given. Calculate F_{oil}/F_{air} and number of stages.





All adjacent (x, y) pairs lie on a line with slope F_{oil}/F_{air}.

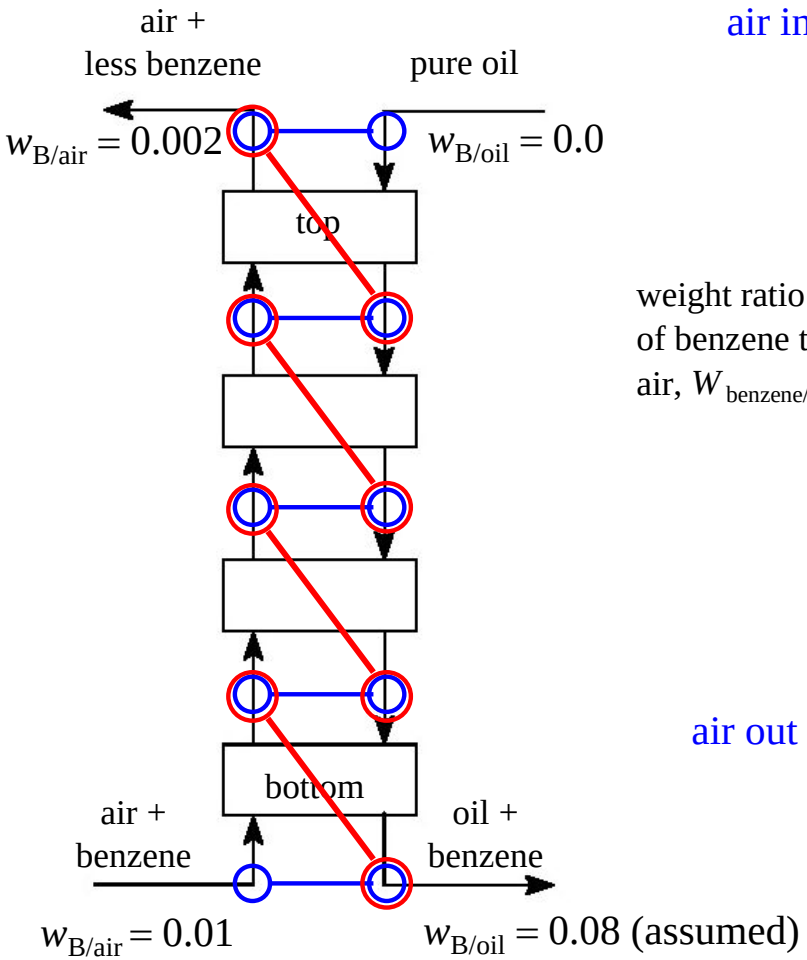
This line is the ***Operating Line***.

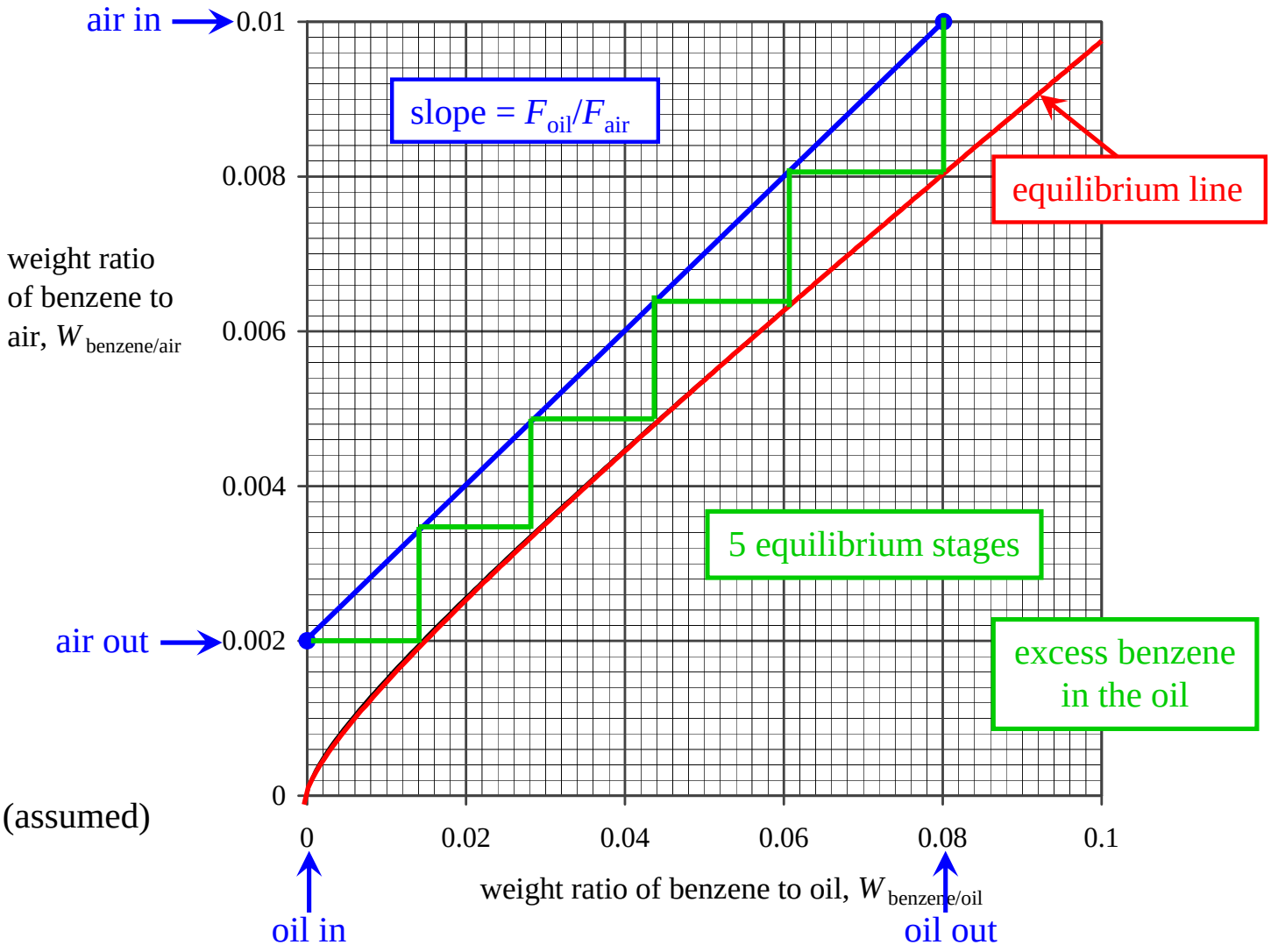
All (x,y) pairs leaving an equilibrium stage lie on the equilibrium line.

1. Plot (x, y) pairs corresponding to top and bottom of absorber column.
2. Draw Operating Line.
3. Step off equilibrium stages.

Graphical Analysis of Multi-Stage Counter-Current Absorbers: Example 2

Decrease F_{oil} (and thus increase $w_{B/oil,out}$).





All adjacent (x, y) pairs lie on a line with slope F_{oil}/F_{air}.

This line is the ***Operating Line***.

All (x,y) pairs leaving an equilibrium stage lie on the equilibrium line.

1. Plot (x, y) pairs corresponding to top and bottom of absorber column.
2. Draw Operating Line.
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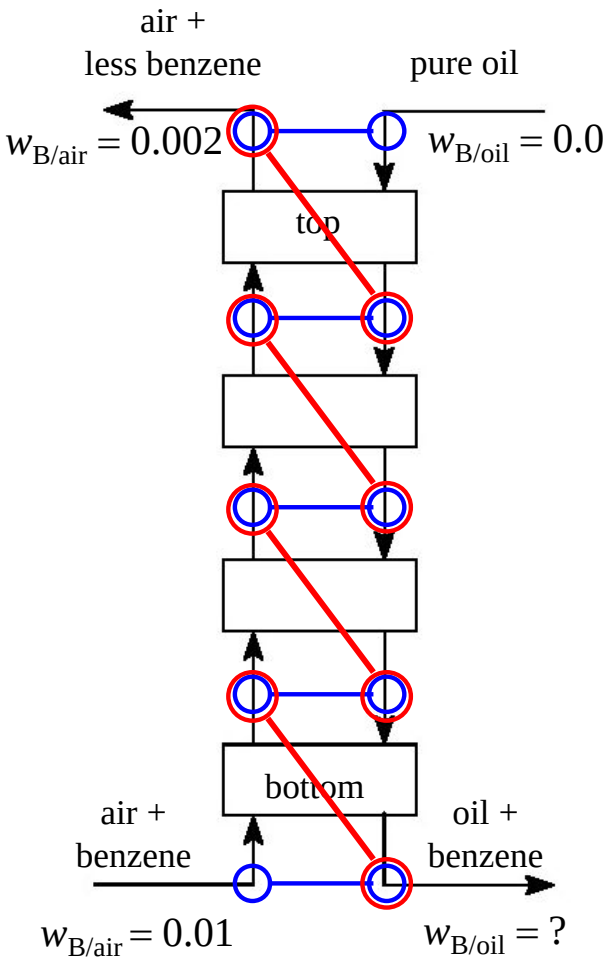
Graphical Analysis of Multi-Stage Counter-Current Absorbers: Example 3

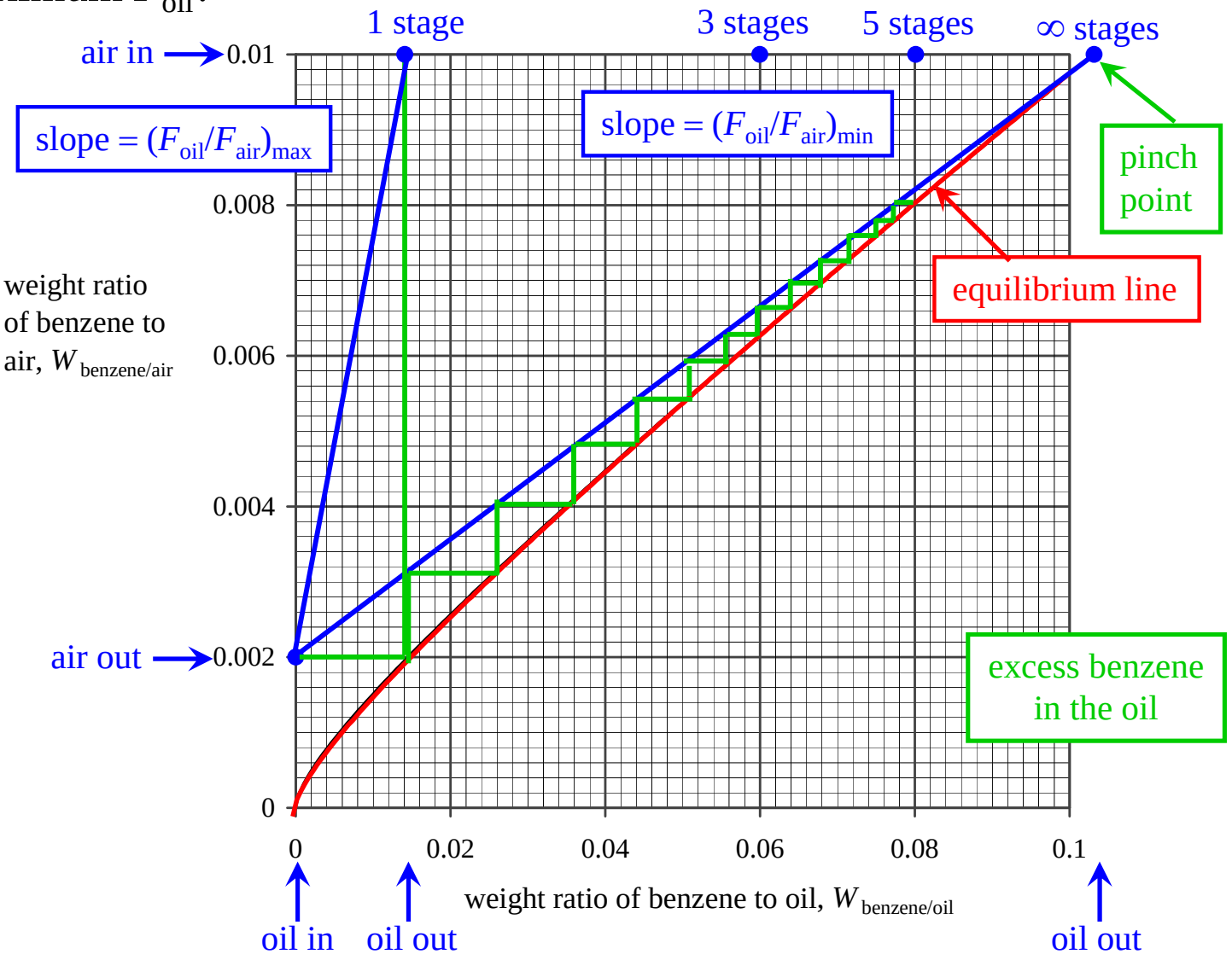
Minimum F_{oil}? Maximum F_{oil}?



All adjacent (x, y) pairs lie on a line with slope F_{oil}/F_{air}.

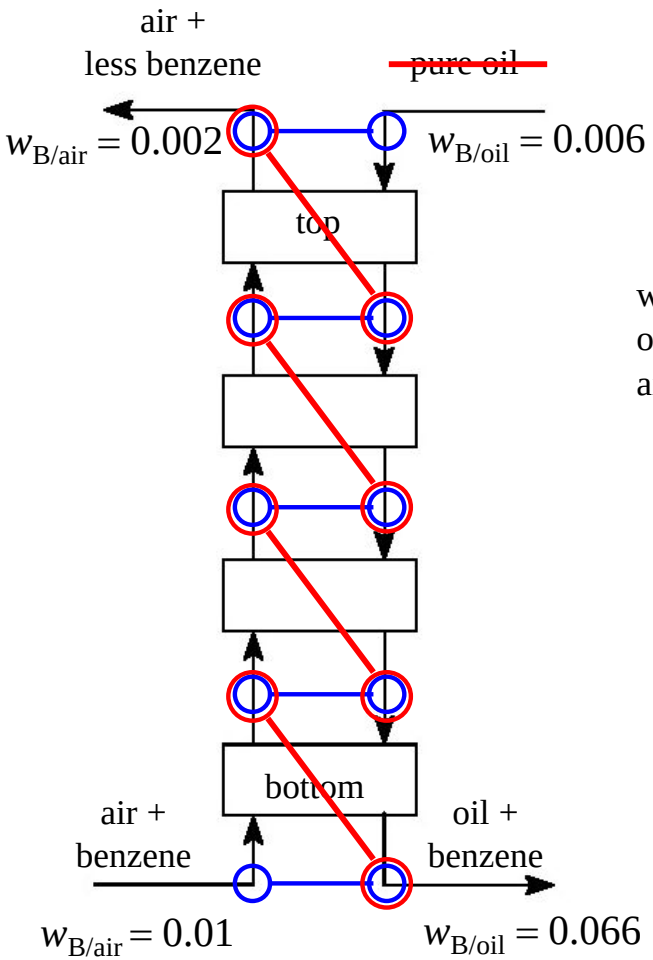
This line is the ***Operating Line***.

All (x,y) pairs leaving an equilibrium stage lie on the equilibrium line.



Graphical Analysis of Multi-Stage Counter-Current Absorbers: Example 4

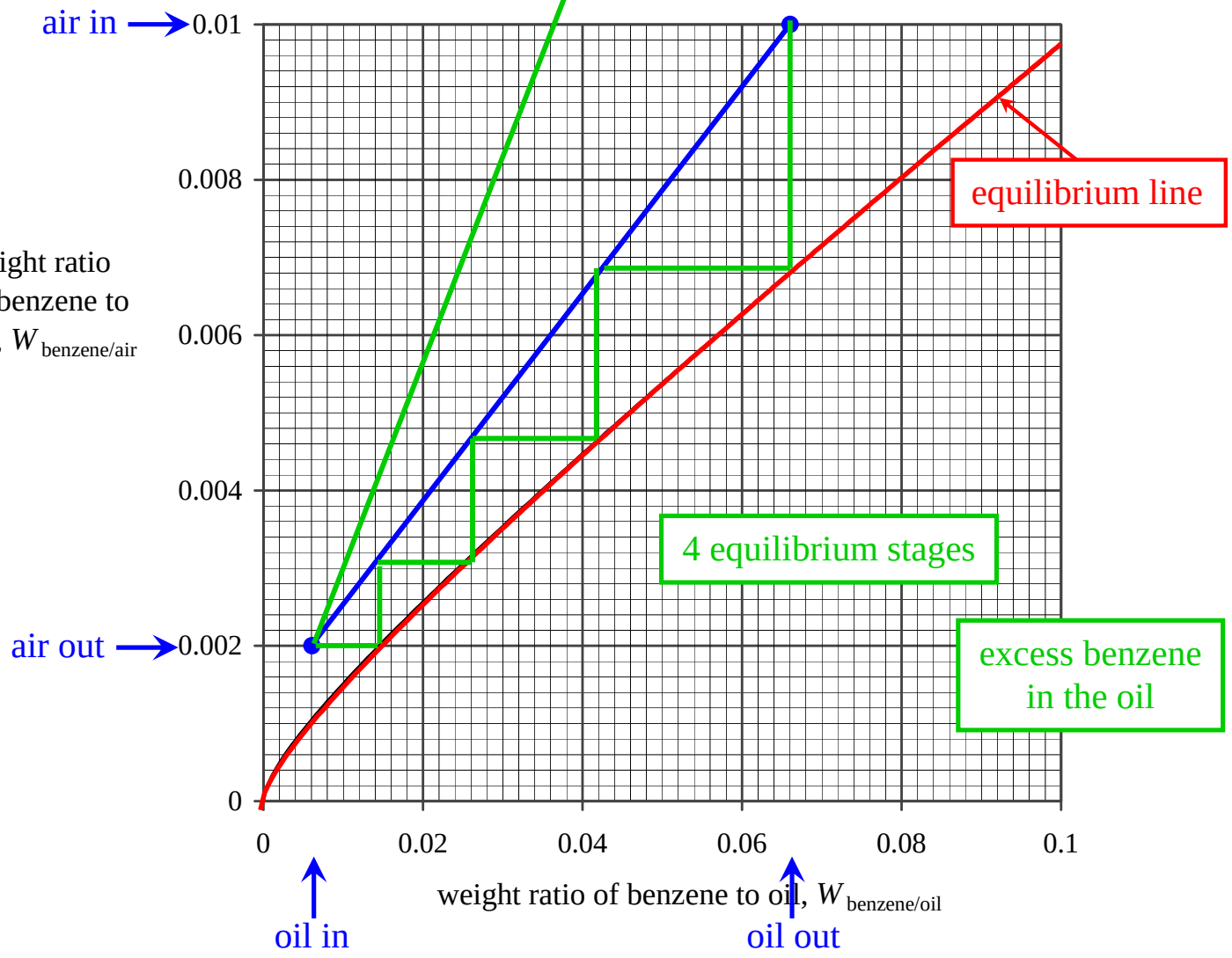
Oil feed contains benzene; F_{oil}/F_{air} same as example 1.



All adjacent (x, y) pairs lie on a line with slope F_{oil}/F_{air}.

This line is the ***Operating Line***.

All (x,y) pairs leaving an equilibrium stage lie on the equilibrium line.



Example 5. Air in contains more benzene; $w_{B/air} = 0.012$.
How to change operating line to reach $w_{B/air} = 0.002$ in 4 stages?