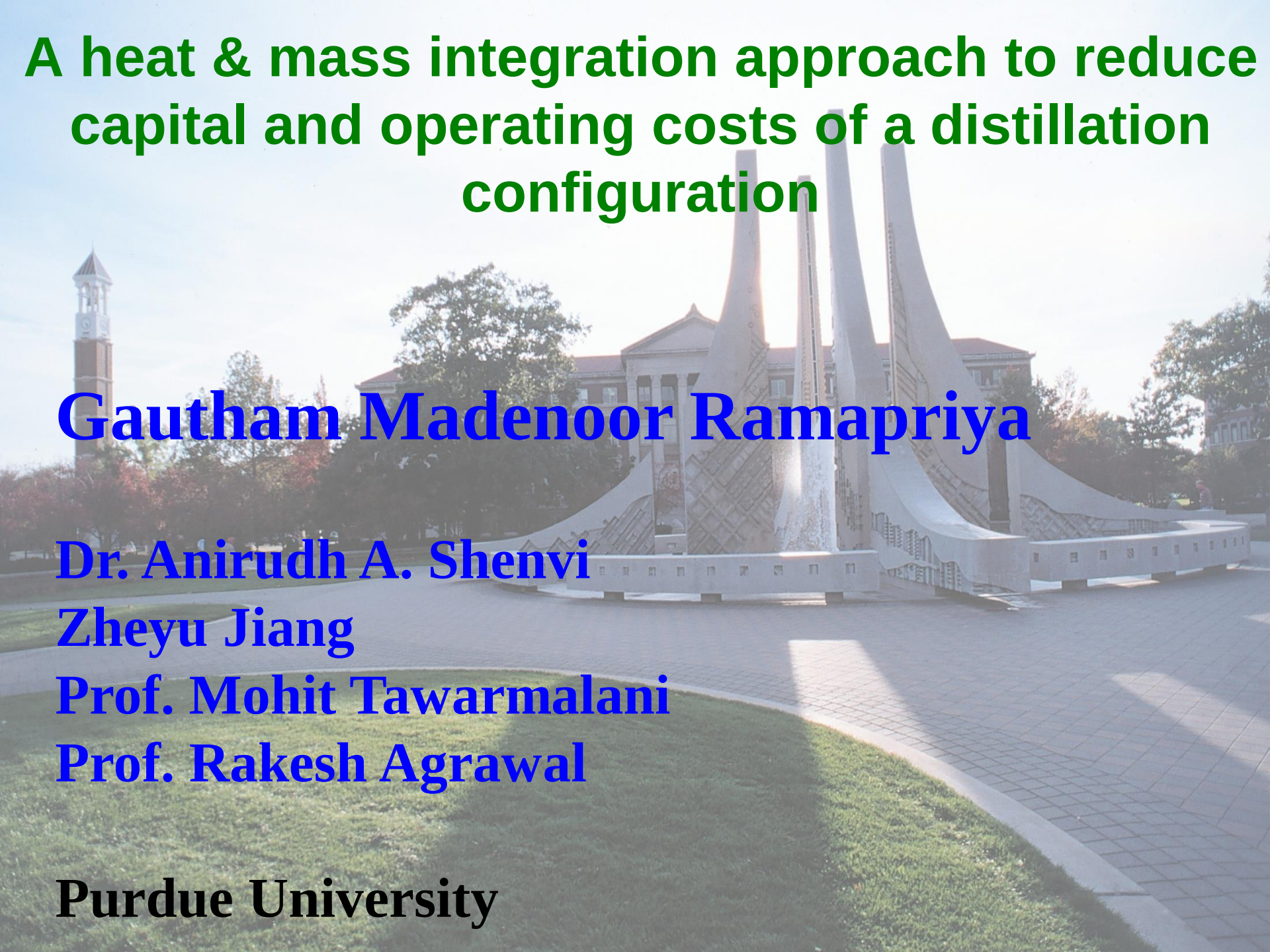
A heat & mass integration approach to reduce capital and operating costs of a distillation configuration

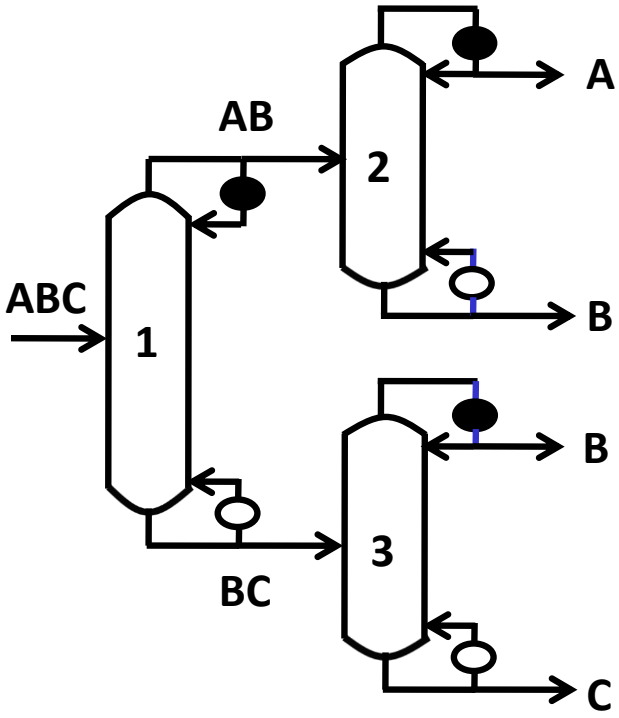


Gautham Madenoor Ramapriya

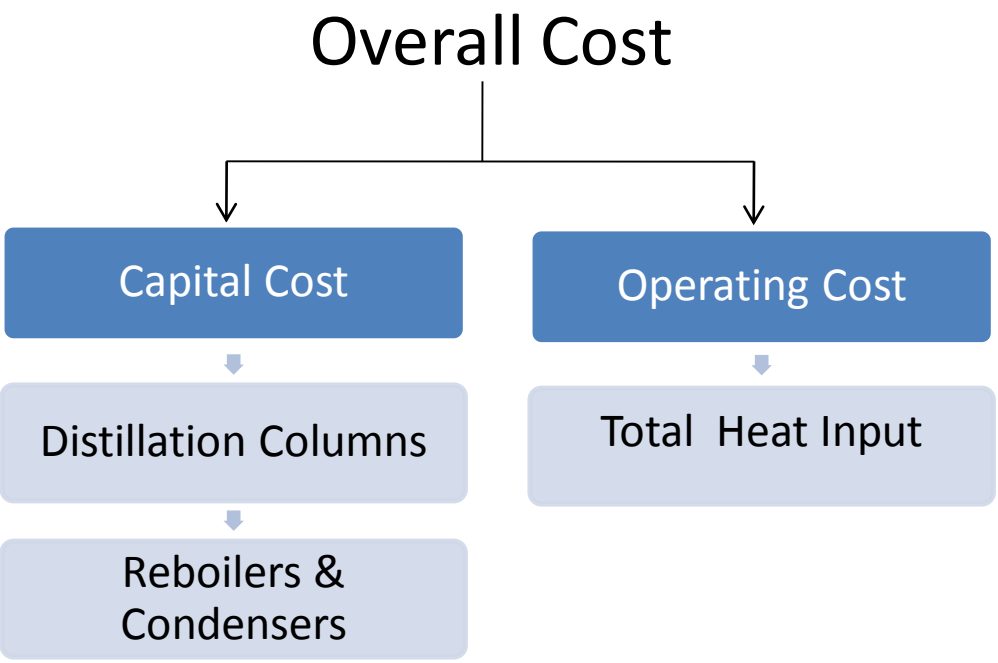
Dr. Anirudh A. Shenvi
Zheyu Jiang
Prof. Mohit Tawarmalani
Prof. Rakesh Agrawal

Purdue University

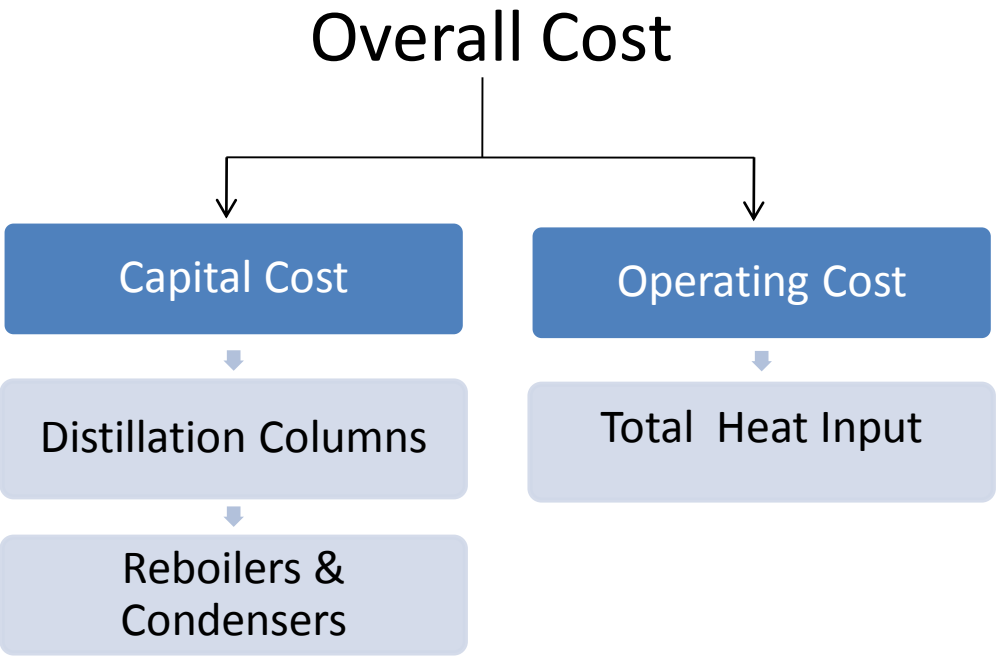
Distillation Configuration



Overall Cost of a Configuration

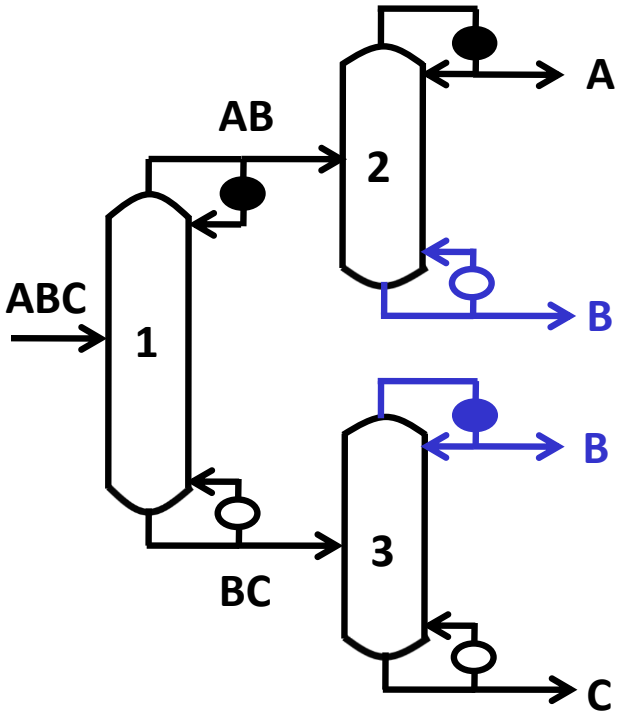


Overall Cost of a Configuration

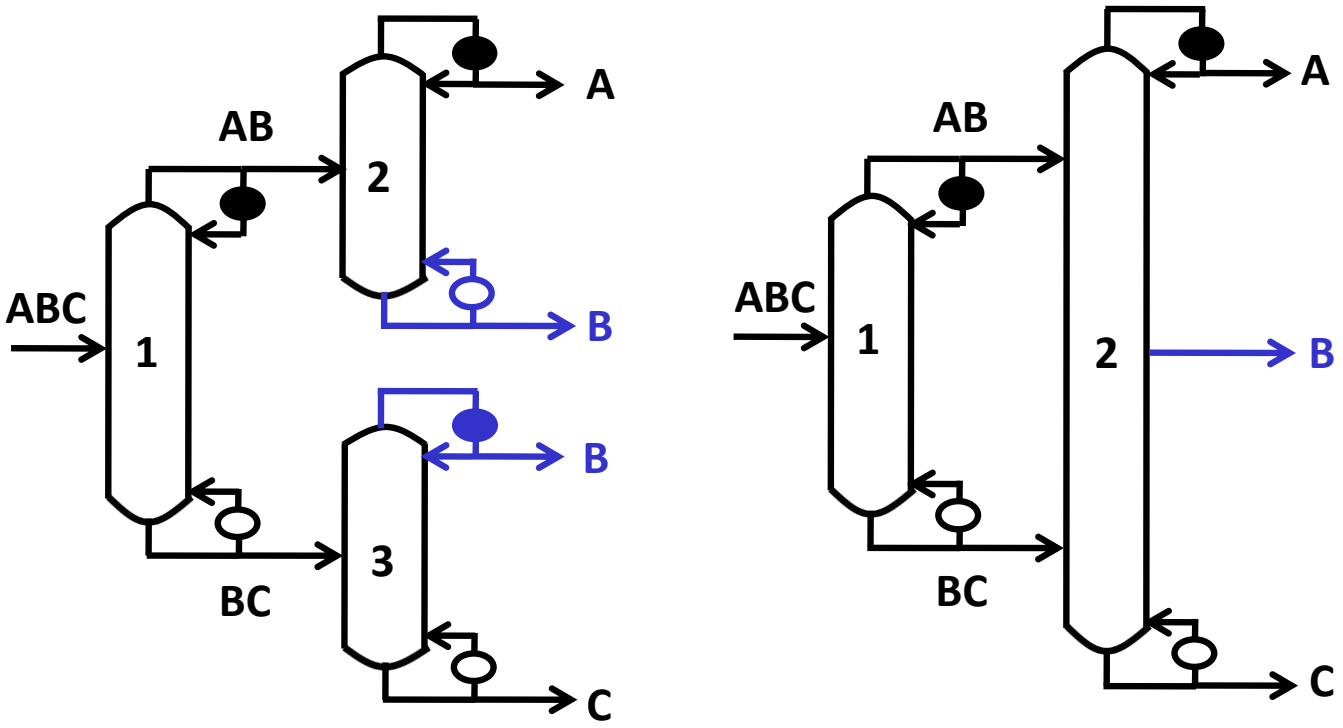


- **Preference ⟶ Reduce both simultaneously**

Heat and Mass Integration

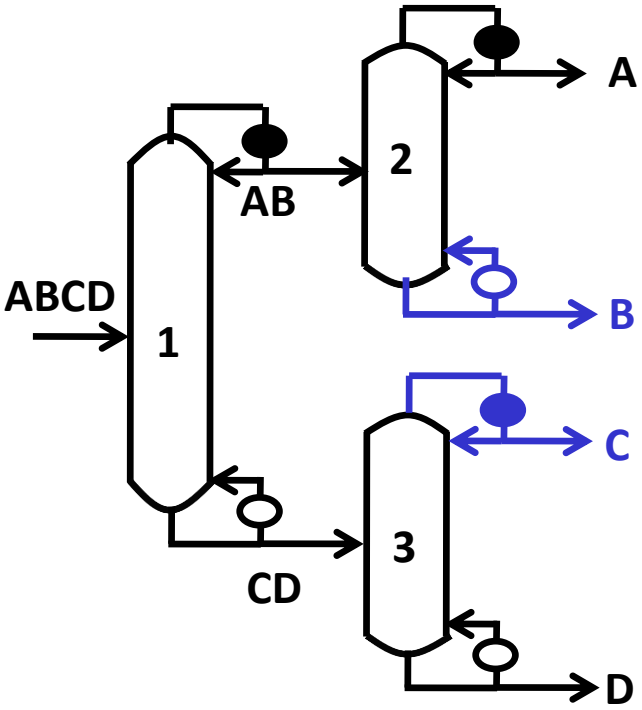


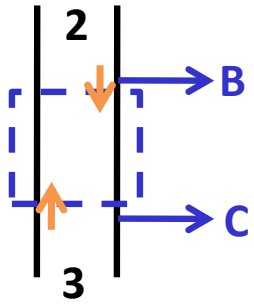
Heat and Mass Integration



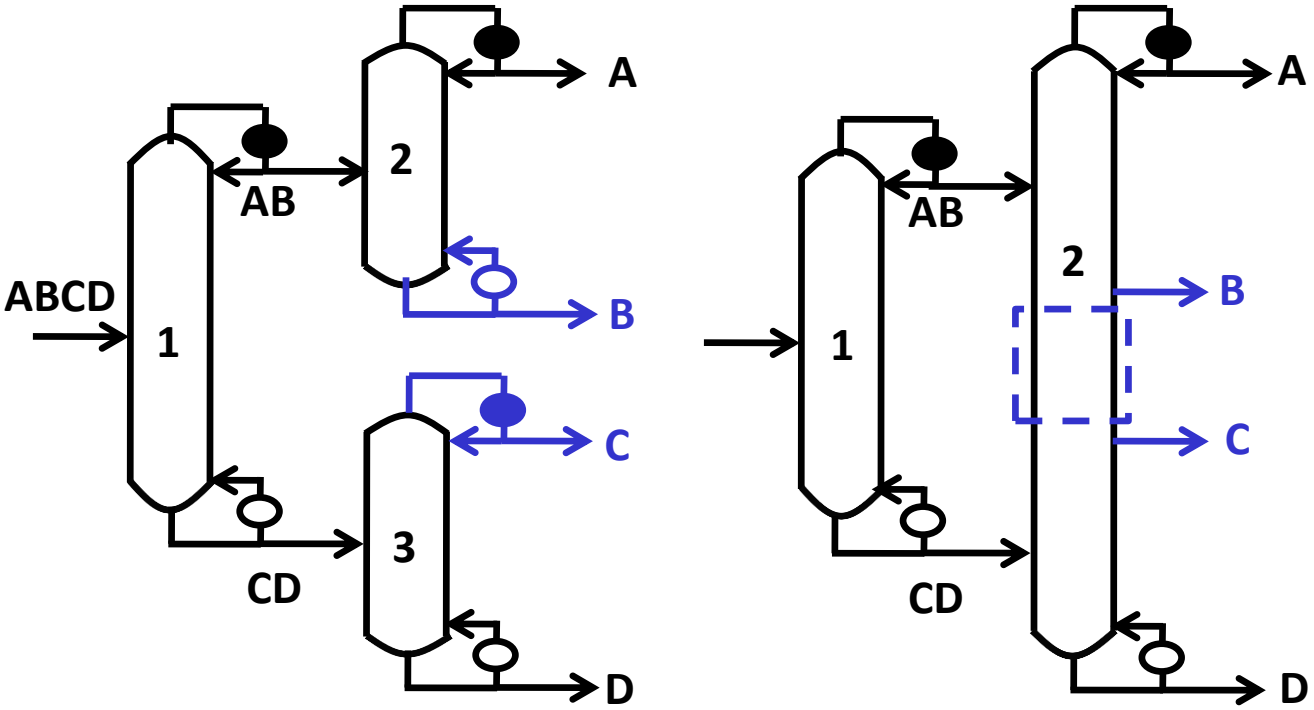
Petlyuk FB, et. al. 1965

Heat and Mass Integration



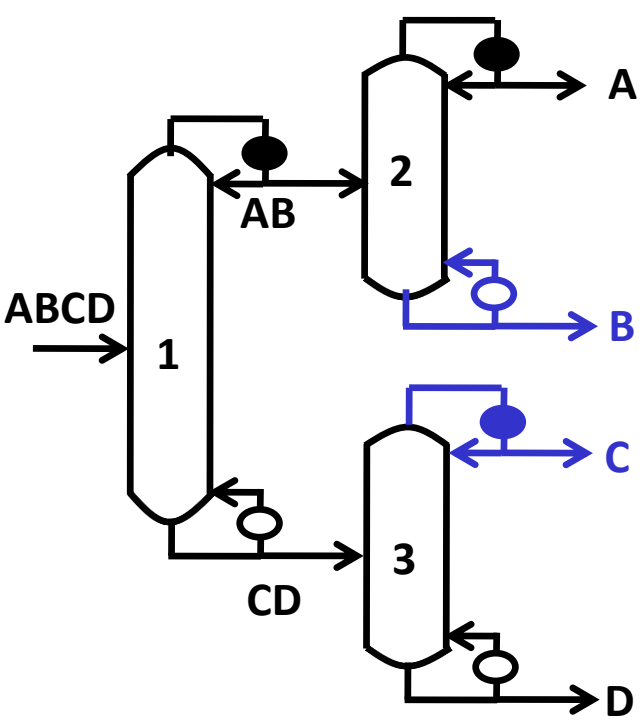


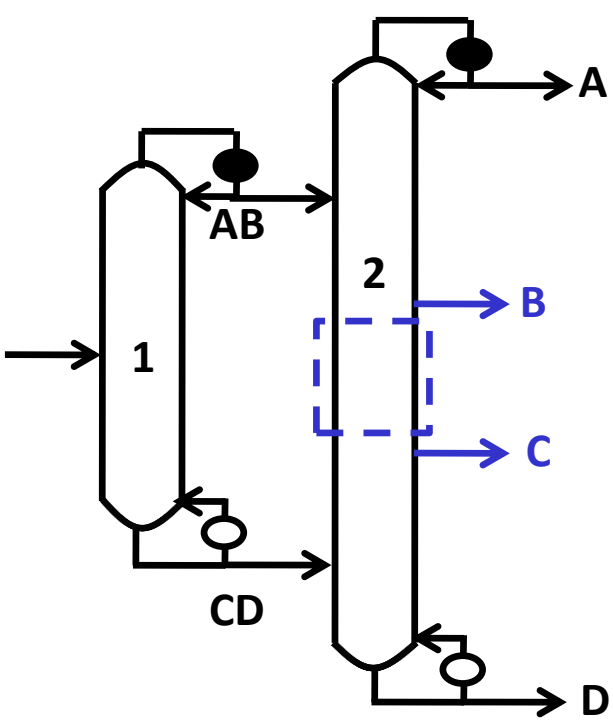
Heat and Mass Integration

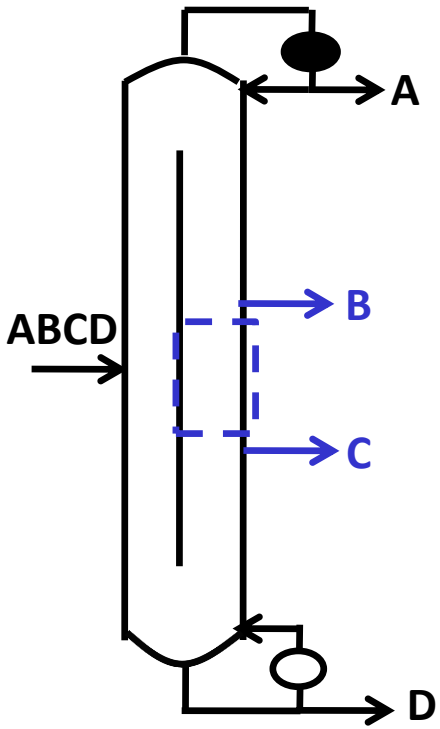


Brugma AJ. 1942

Heat and Mass Integration

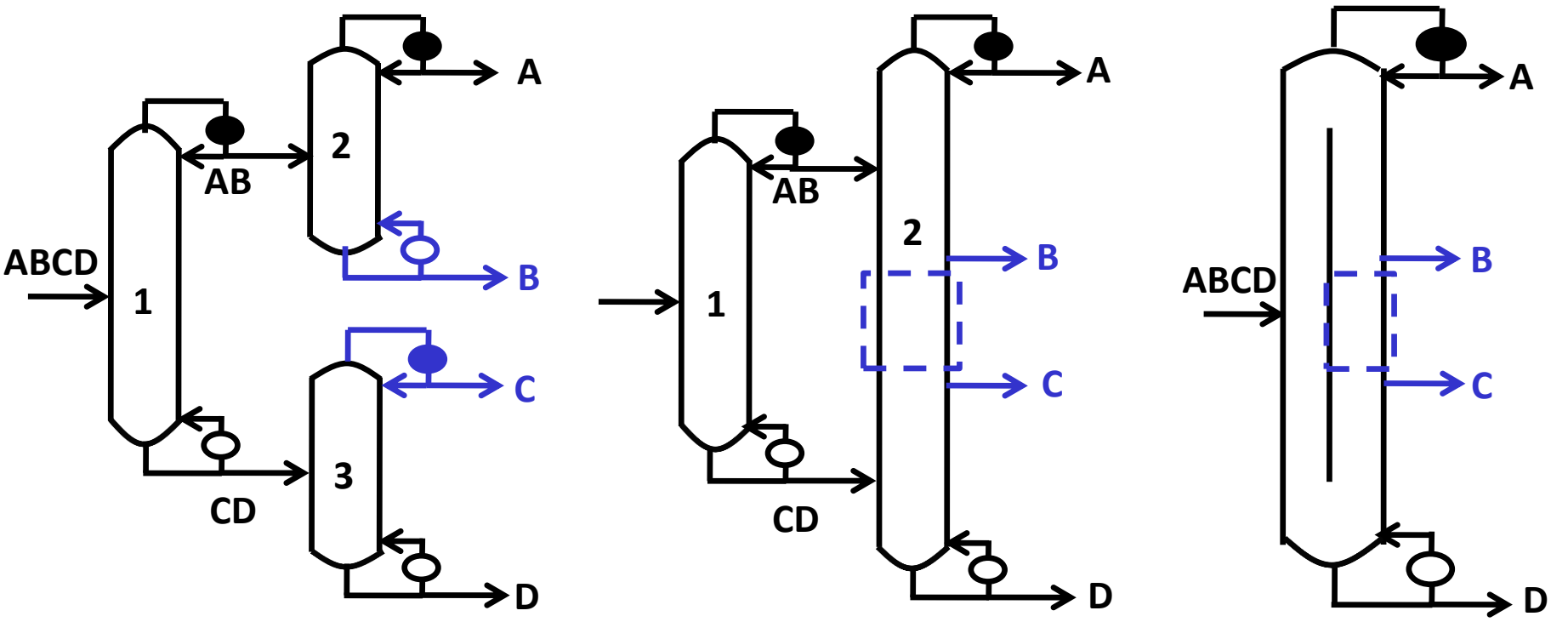






Brugma AJ. 1942; Kaibel G. 1987

Heat and Mass Integration

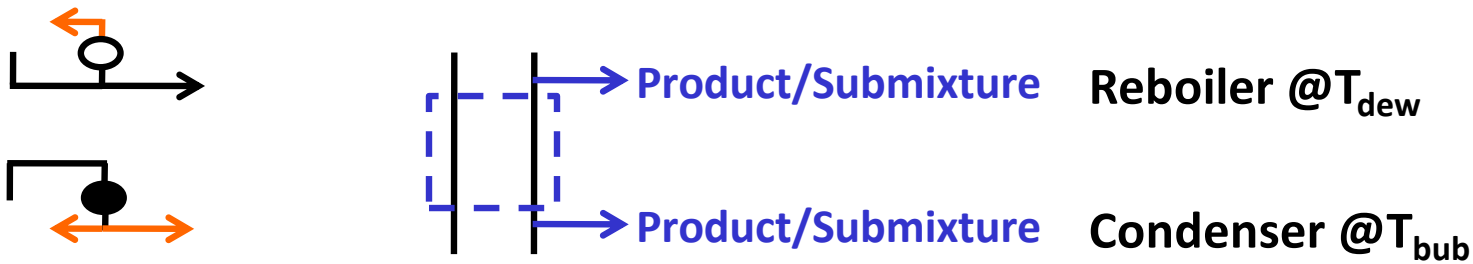


Heat & Mass integration with Additional section (HMA)

Brugma AJ. 1942; Kaibel G. 1987

Heat and Mass Integration with Additional Section (HMA)

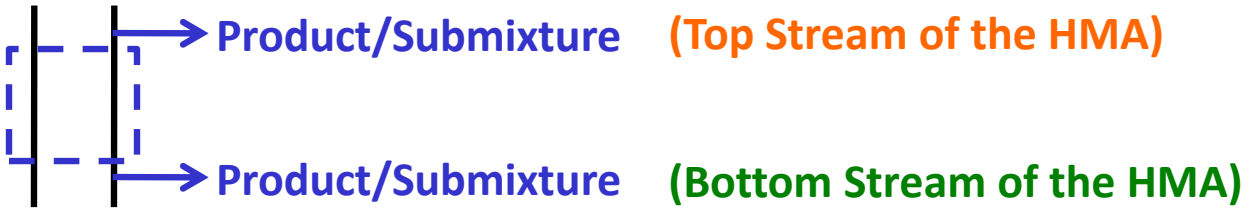
- **Generalized Framework for Heat and Mass Integration Between the Condenser of a Distillation column and the Reboiler of Another Distillation Column**



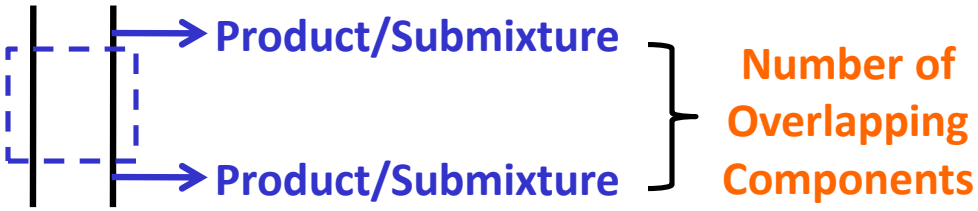
$T_{bub} > T_{dew}$

Heat and Mass Integration with Additional Section (HMA)

- **Generalized Framework for Heat and Mass Integration Between the Condenser of a Distillation column and the Reboiler of Another Distillation Column**



Categorization of HMAs

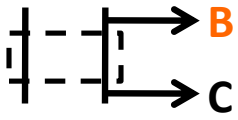


- HMAs with no overlap
- HMAs with one overlap
- HMAs with two overlaps
- HMAs with three overlaps

⋮

Examples of HMA: No Overlap

Single-Single



Examples of HMA: No Overlap

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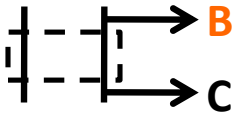
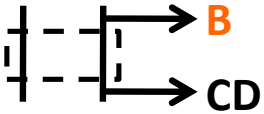
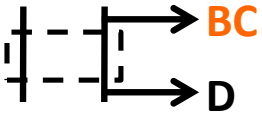


Single-Binary

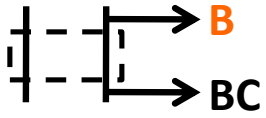


Binary-Single

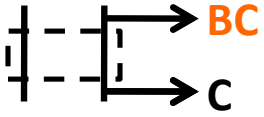


Examples of HMA: One Overlap

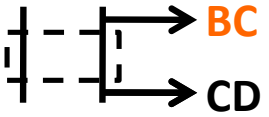
Single-Binary



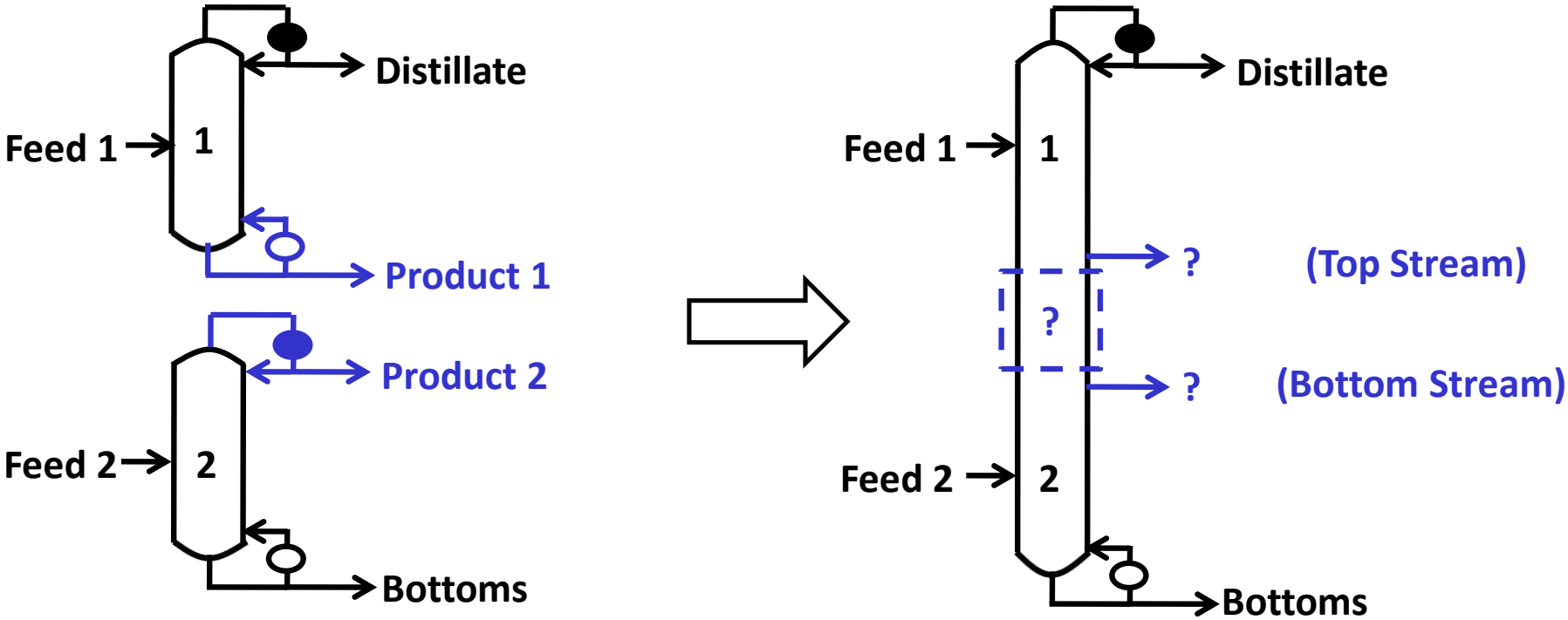
Binary-Single



Binary-Binary

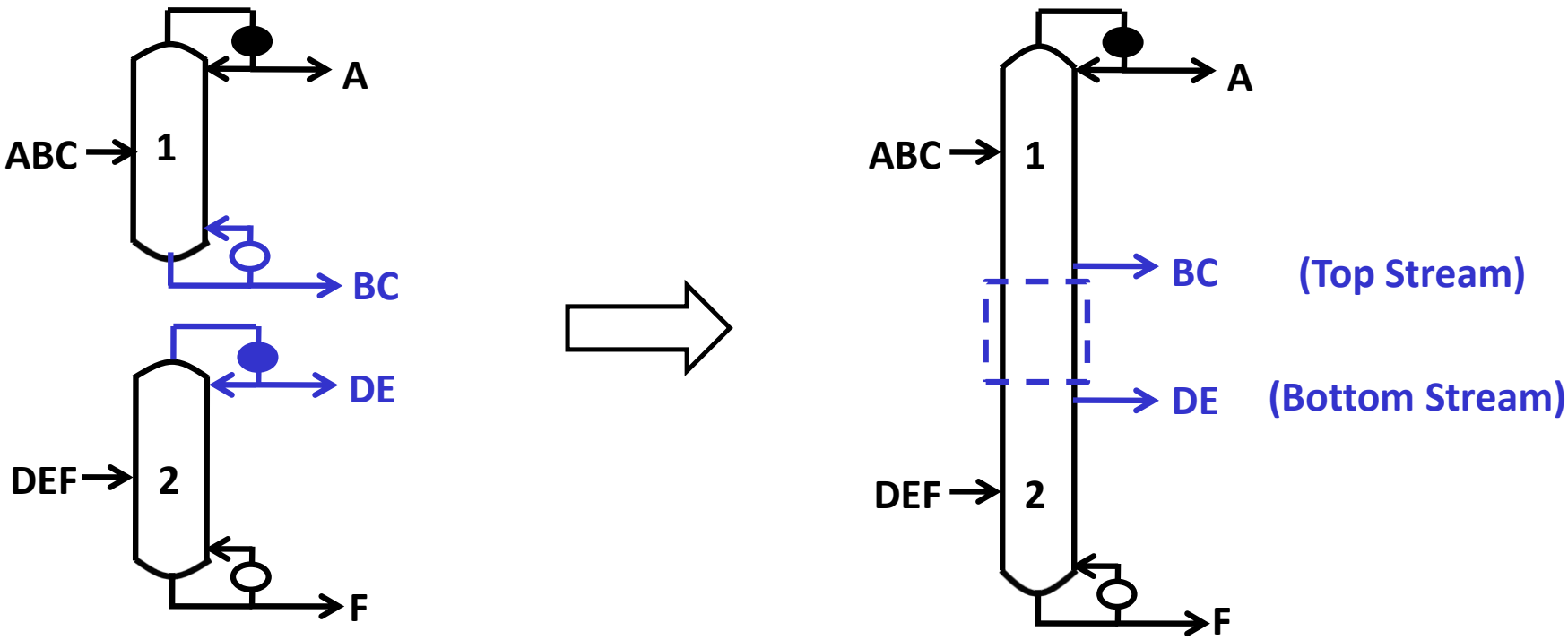


Study of the Operational Aspects of HMAs

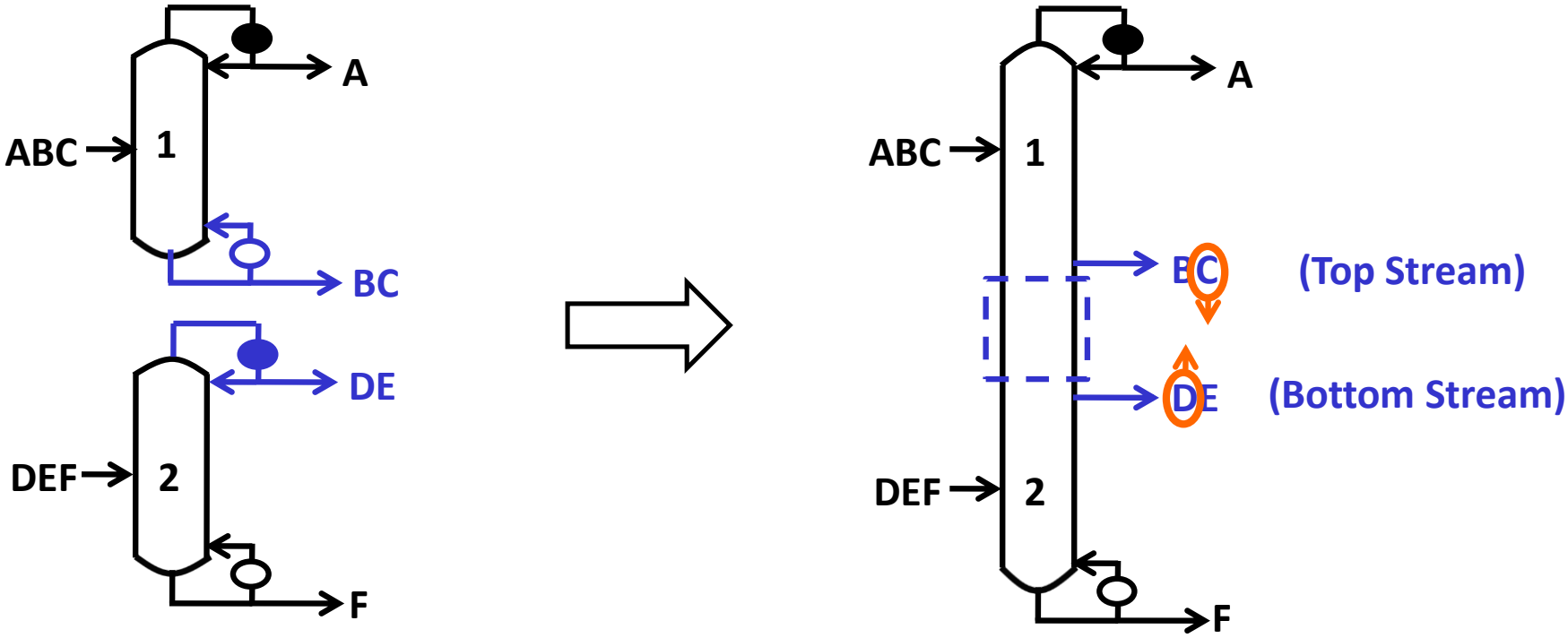


No net mass flow section

HMA: No Overlap

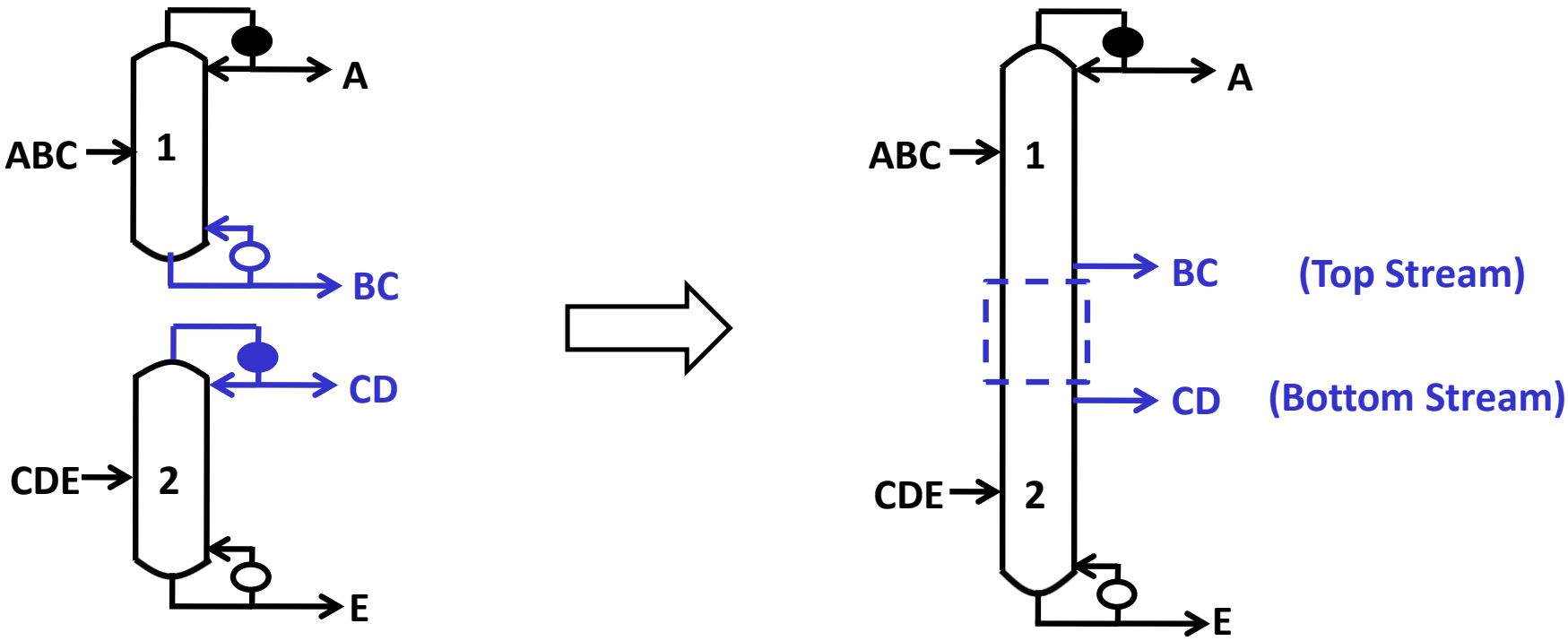


HMA: No Overlap

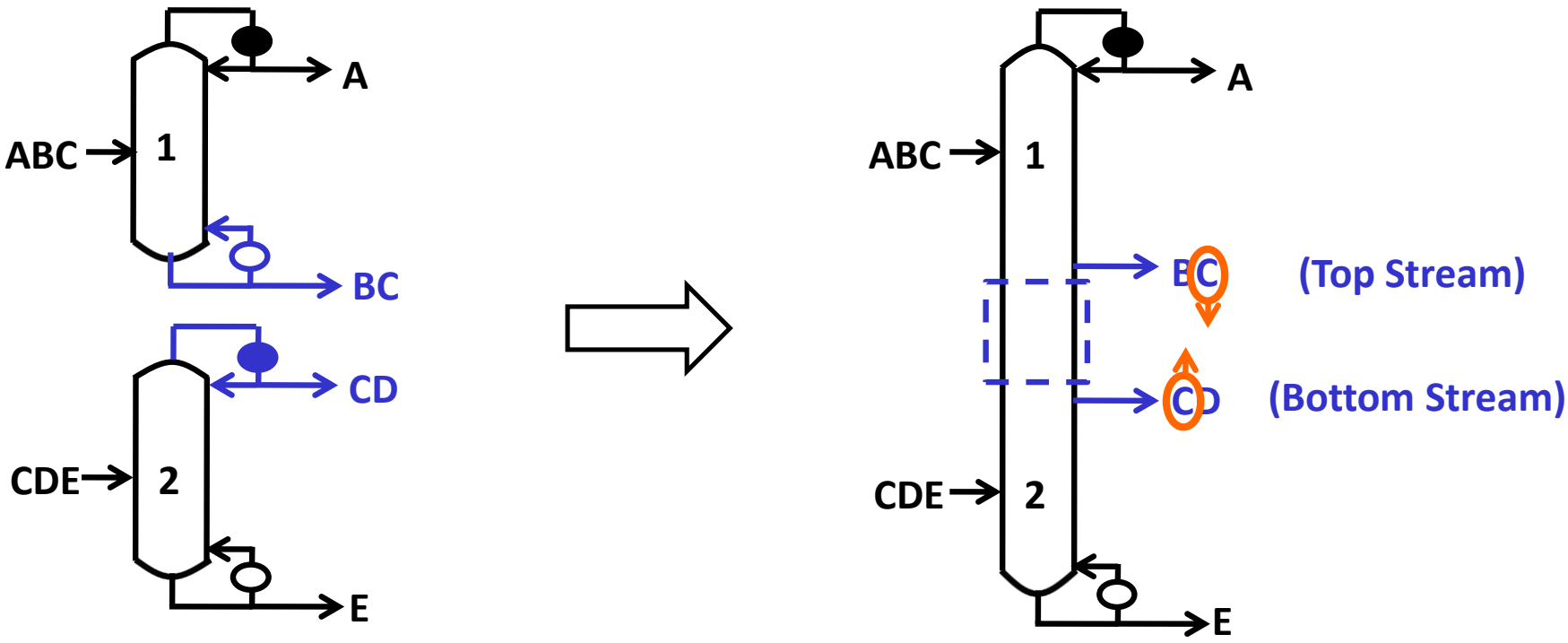


- $\alpha_C > \alpha_D$
- composition retained (sufficient number of stages)
- α_{CD}
- vapor flow

HMA: One Overlap



HMA: One Overlap

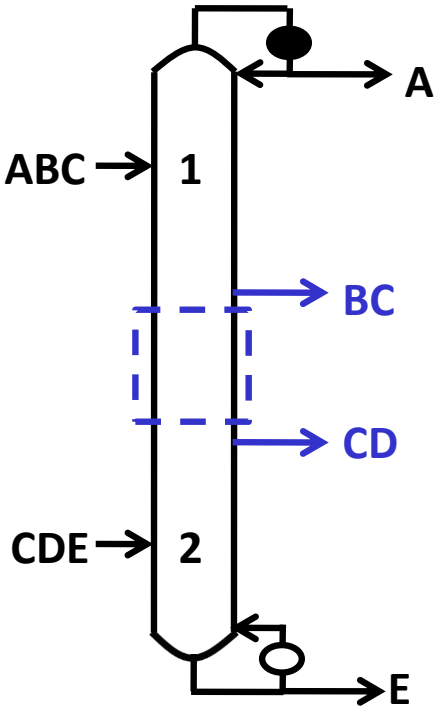


- $\alpha_C = \alpha_C$
- composition retained (sufficient number of stages)

HMA: One Overlap

- For $\{\alpha_{BC}, \alpha_{CD}\} = \{1.1, 1.1\}$, at BR=4 (> BR_{min} = 3.3)

BC Flowrate	*CD* Flowrate	Net Mass	Net *B*	Net *C*	Net *D*	Direction of component flows
kmol/hr						
56	44	6	0	5.545	0.455	
55	45	5	0	4.989	0.011	+C, +D
54	46	4	0	3.999	0.001	
53	47	3	0	3	0	
52	48	2	0	2	0	+C
51	49	1	0	1	0	
50	50	0	0	0	0	
49	51	-1	0	-1	0	
48	52	-2	0	-2	0	-C
47	53	-3	0	-3	0	
46	54	-4	-0.001	-3.999	0	
45	55	-5	-0.002	-4.998	0	-B, -C
44	56	-6	-0.011	-5.989	0	



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52	48	2	0	2	0	↑C
51	49	1	0	1	0	
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49	51	-1	0	-1	0	
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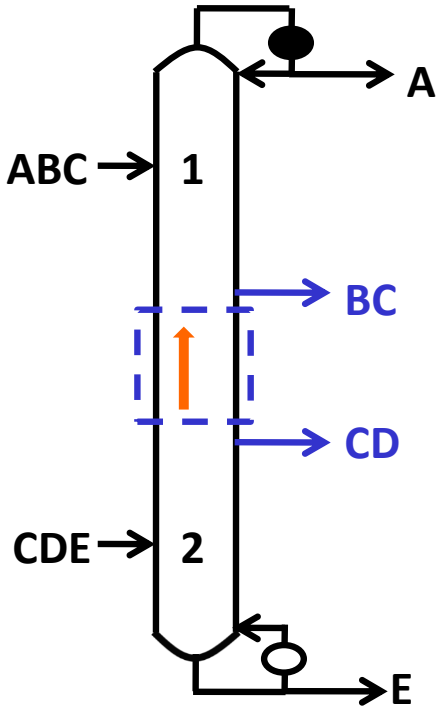

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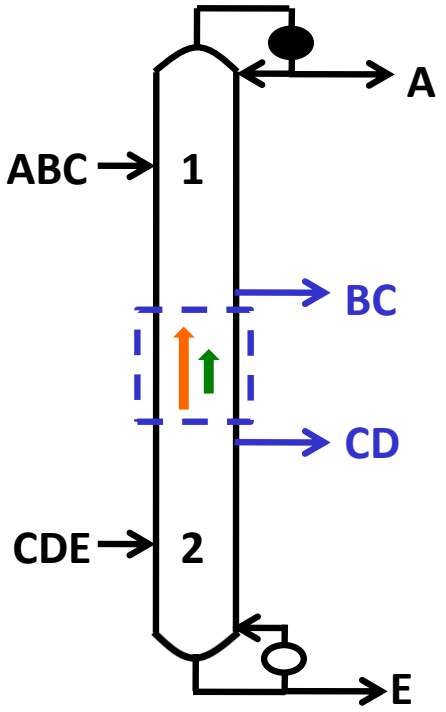

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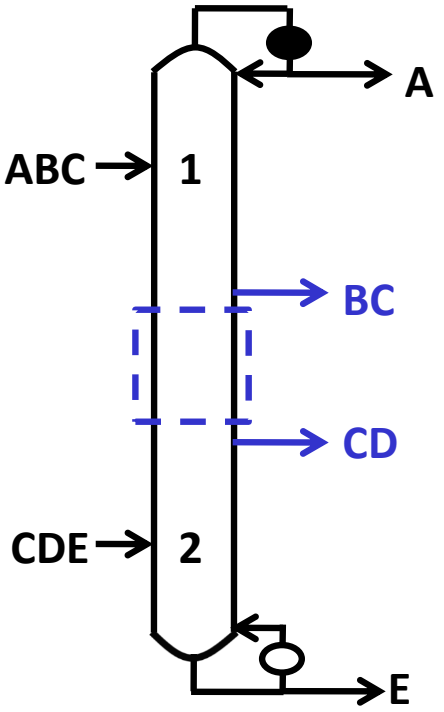

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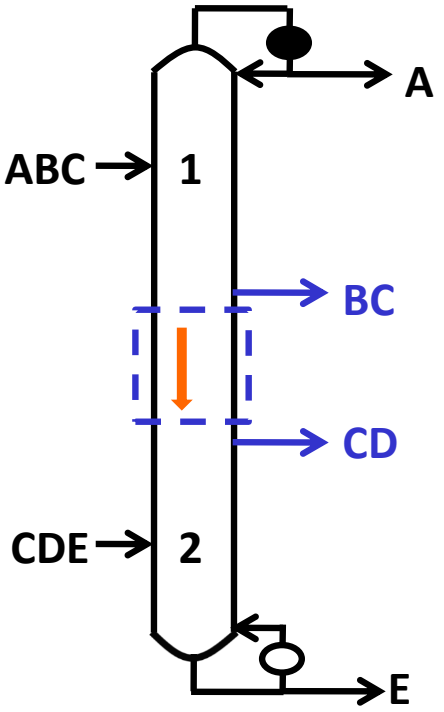
50	50	0	0	0	0	
49	51	-1	0	-1	0	
48	52	-2	0	-2	0	C
47	53	-3	0	-3	0	
46	54	-4	-0.001	-3.999	0	
45	55	-5	-0.002	-4.998	0	-B, -C
44	56	-6	-0.011	-5.989	0	



HMA: One Overlap

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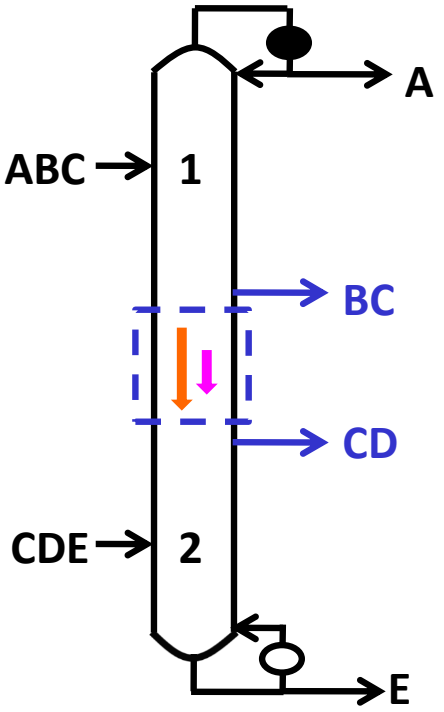
51	49	1	0	1	0	
50	50	0	0	0	0	
49	51	-1	0	-1	0	
48	52	-2	0	-2	0	↓C
47	53	-3	0	-3	0	
46	54	-4	-0.001	-3.999	0	
45	55	-5	-0.002	-4.998	0	↓B ↓C
44	56	-6	-0.011	-5.989	0	



HMA: One Overlap

- For $\{\alpha_{BC}, \alpha_{CD}\} = \{1.1, 1.1\}$, at BR=4 (> BR_{min} = 3.3)

BC Flowrate	*CD* Flowrate	Net Mass	Net *B*	Net *C*	Net *D*	Direction of component flows
kmol/hr						
56	44	6	0	5.545	0.455	C ↑D
55	45	5	0	4.989	0.011	
54	46	4	0	3.999	0.001	
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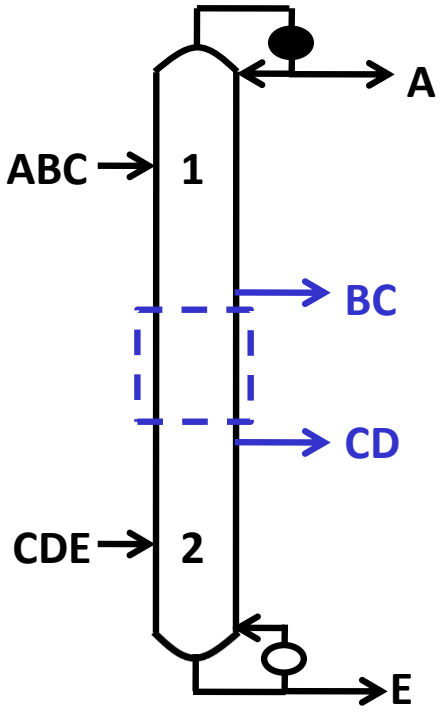
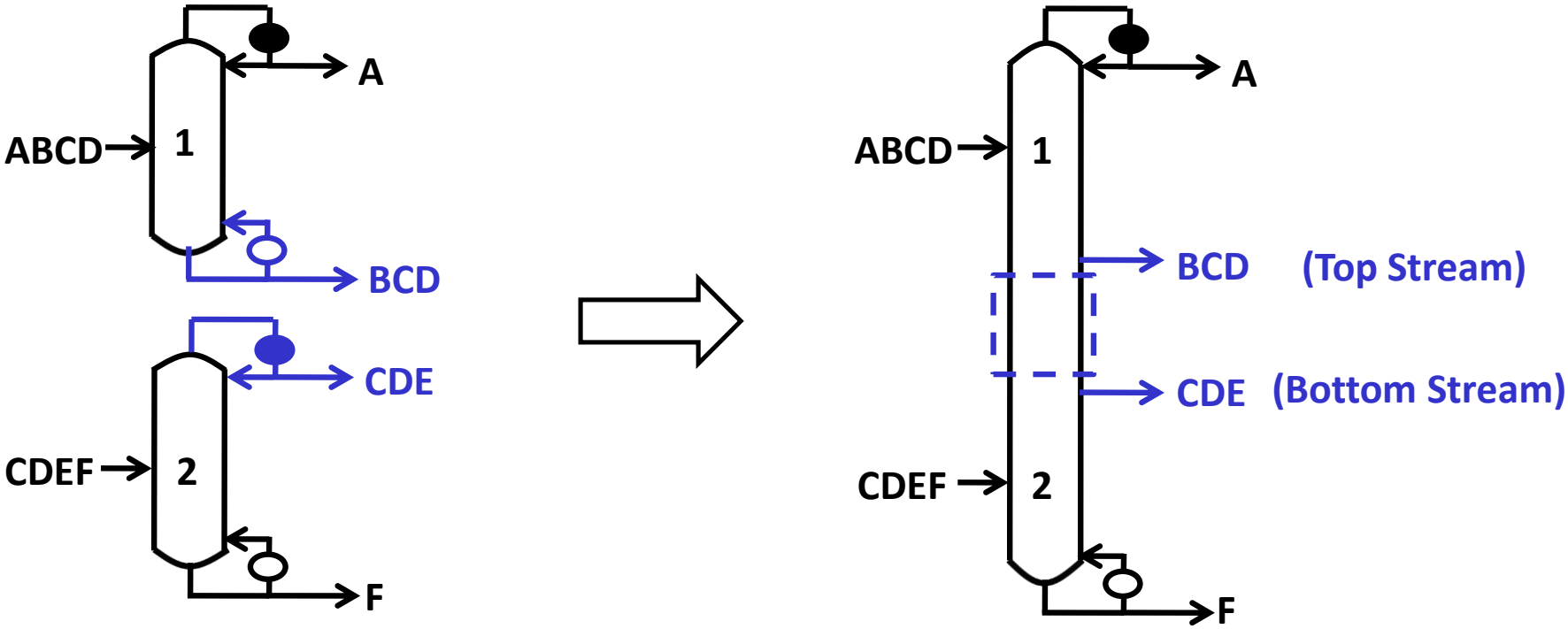
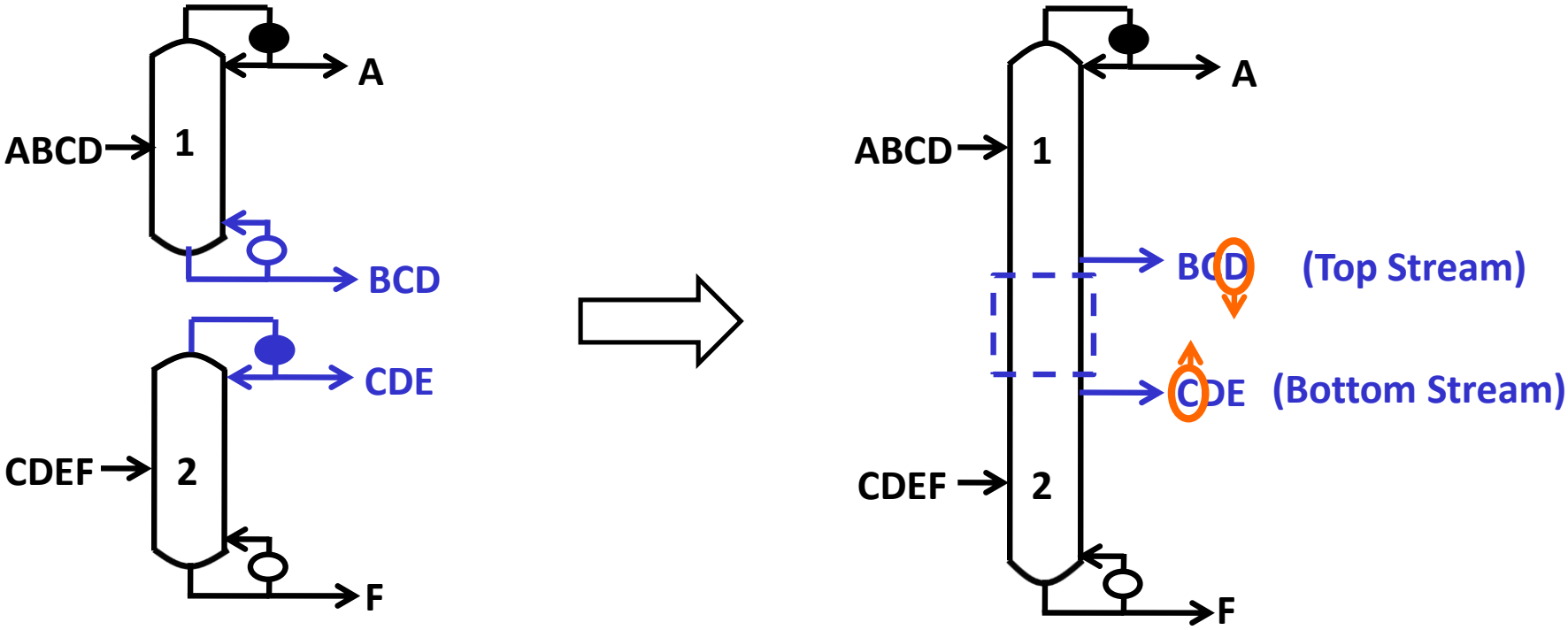


HMA: Two Overlaps



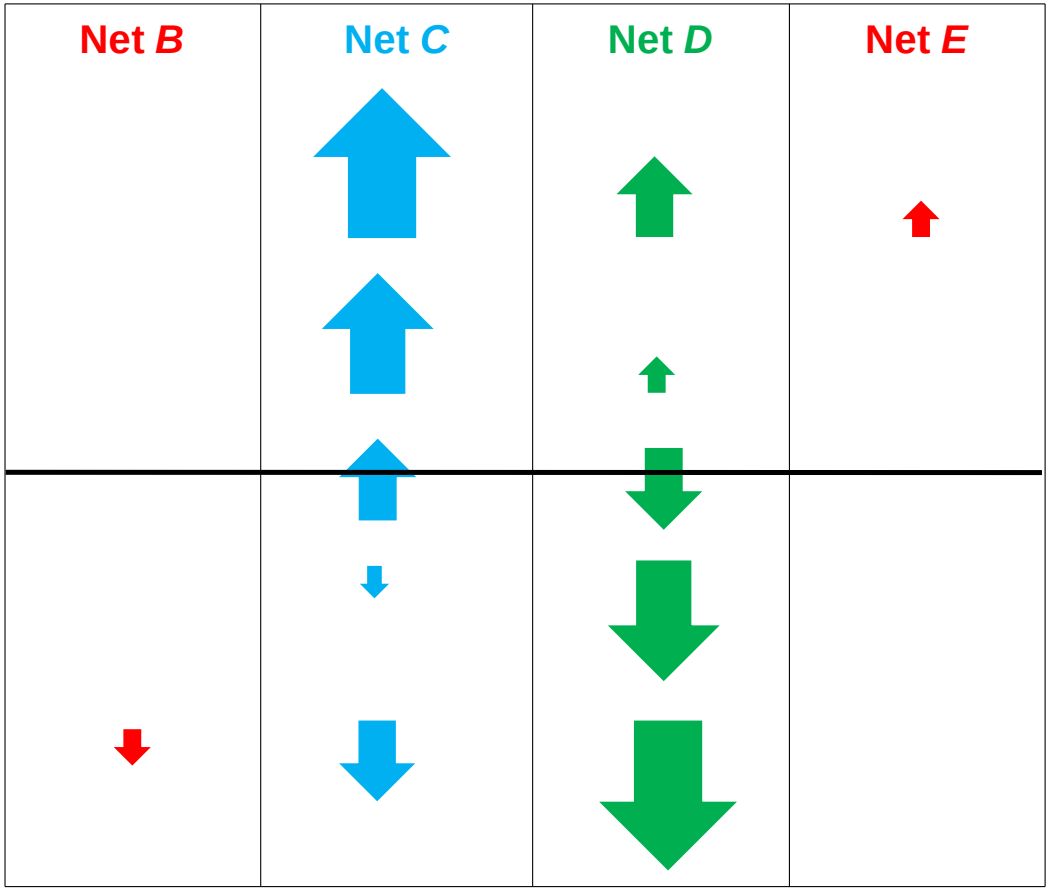
HMA: Two Overlaps

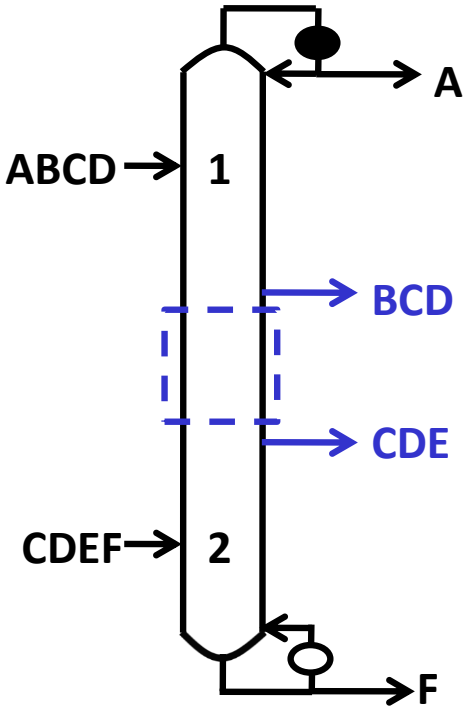


- $\alpha_C > \alpha_D$
- composition not retained (sufficient number of stages)

HMA: Two Overlaps

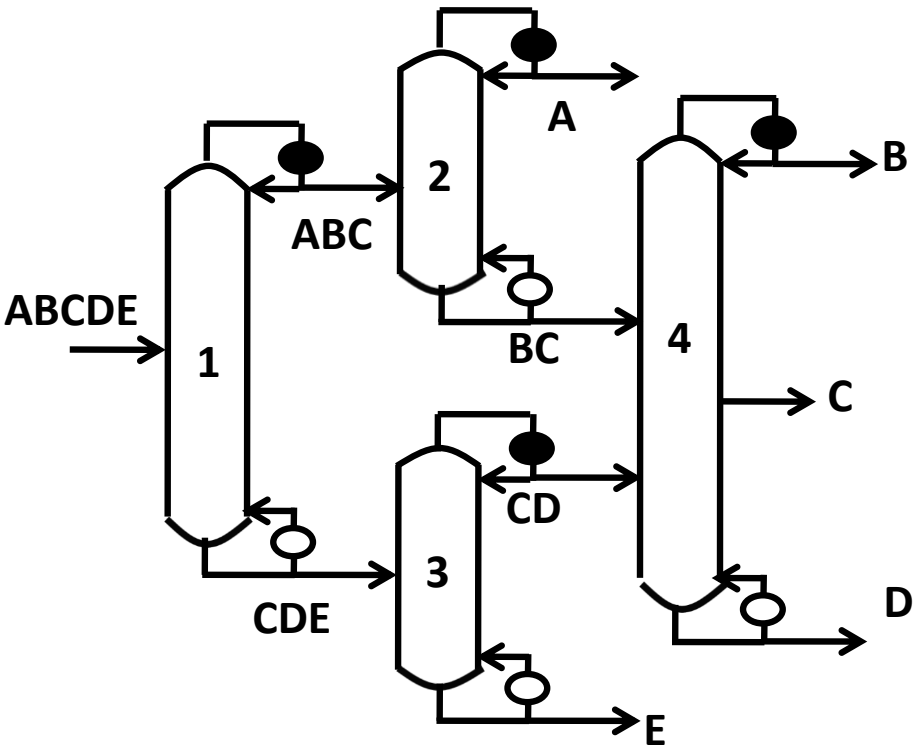
- For $\{\alpha_{BC}, \alpha_{CD}, \alpha_{DE}\} = \{1.1, 1.1, 1.1\}$, at BR=5 (> BR_{min} = 4.46)





Heat Duty Benefits: HMAs

- **Equimolar feed; All transfer streams including feed: liquid phase**
  $\alpha_{A,B} = \alpha_{B,C} = 2.5$
  $\alpha_{C,D} = \alpha_{D,E} = 1.5$



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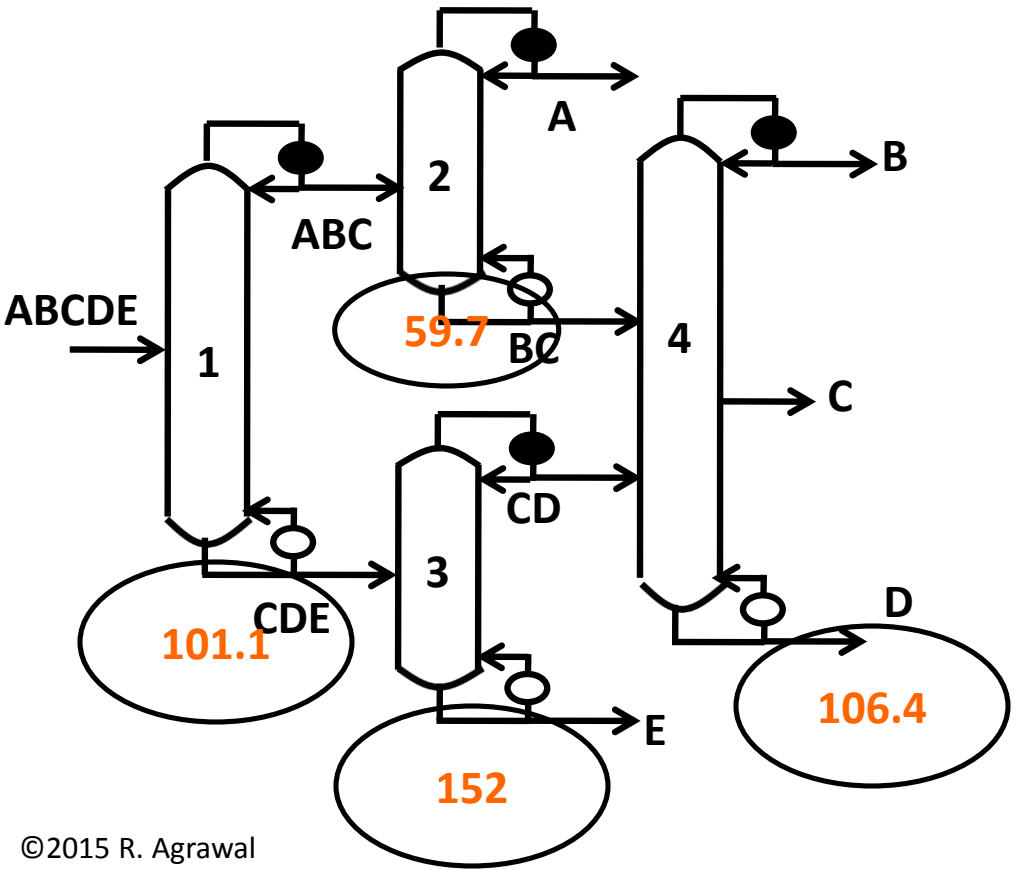

Heat Duty Benefits: HMAs

- **Equimolar feed; All transfer streams including feed: liquid phase**

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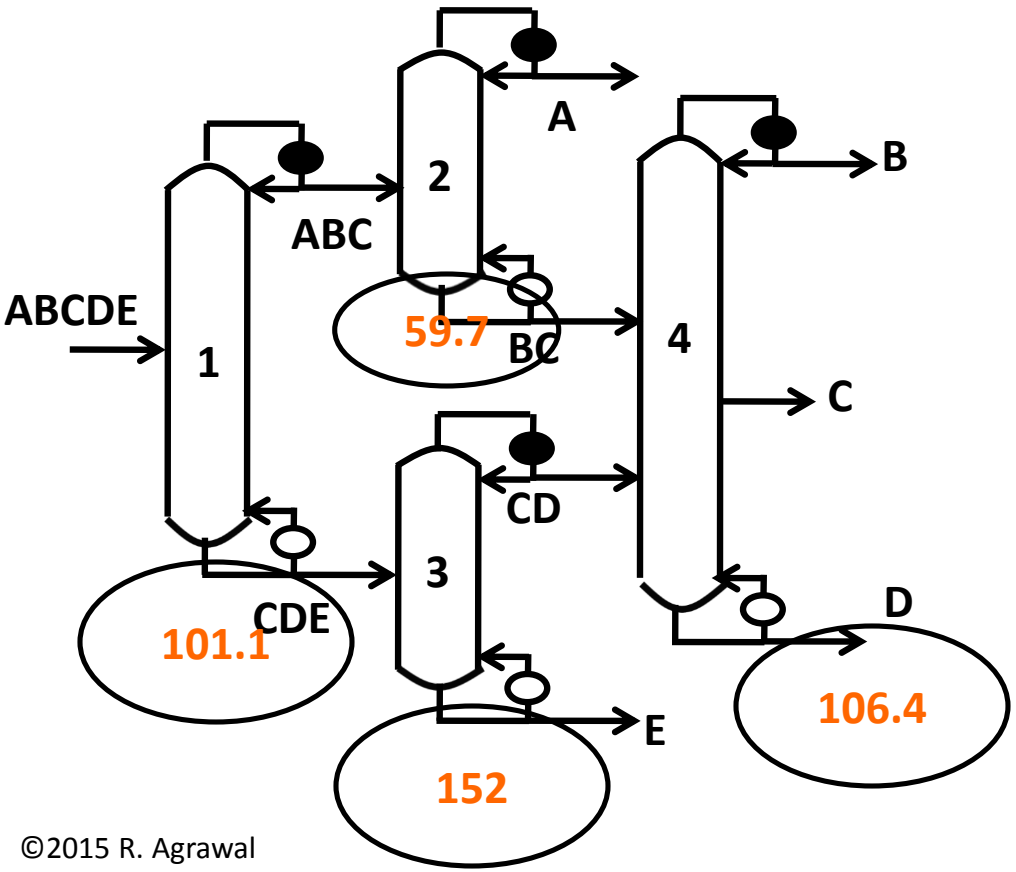
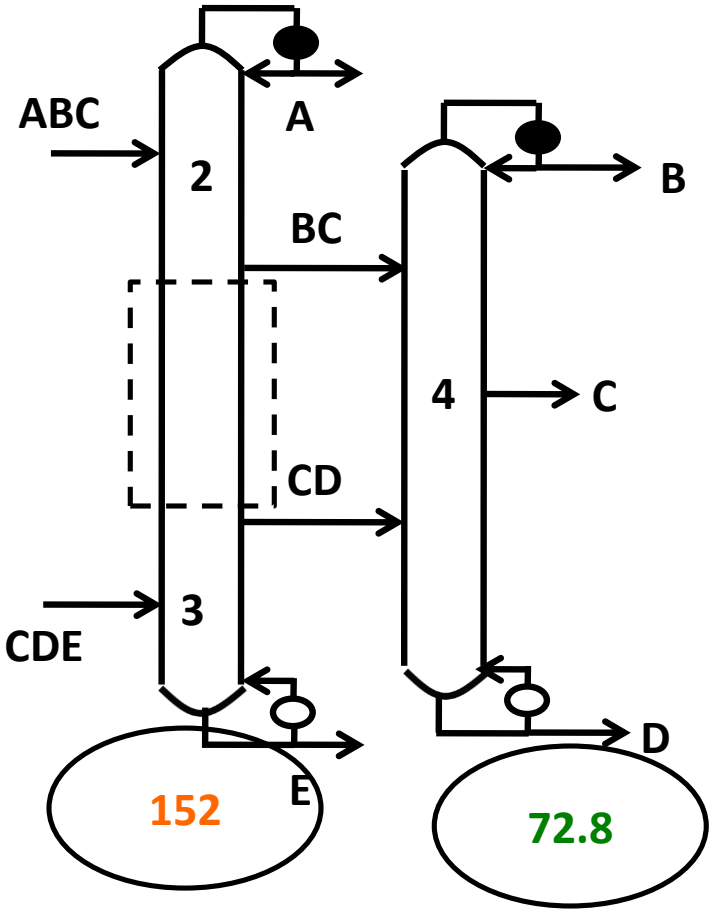


Overall Heat Duty Savings = 22.2%



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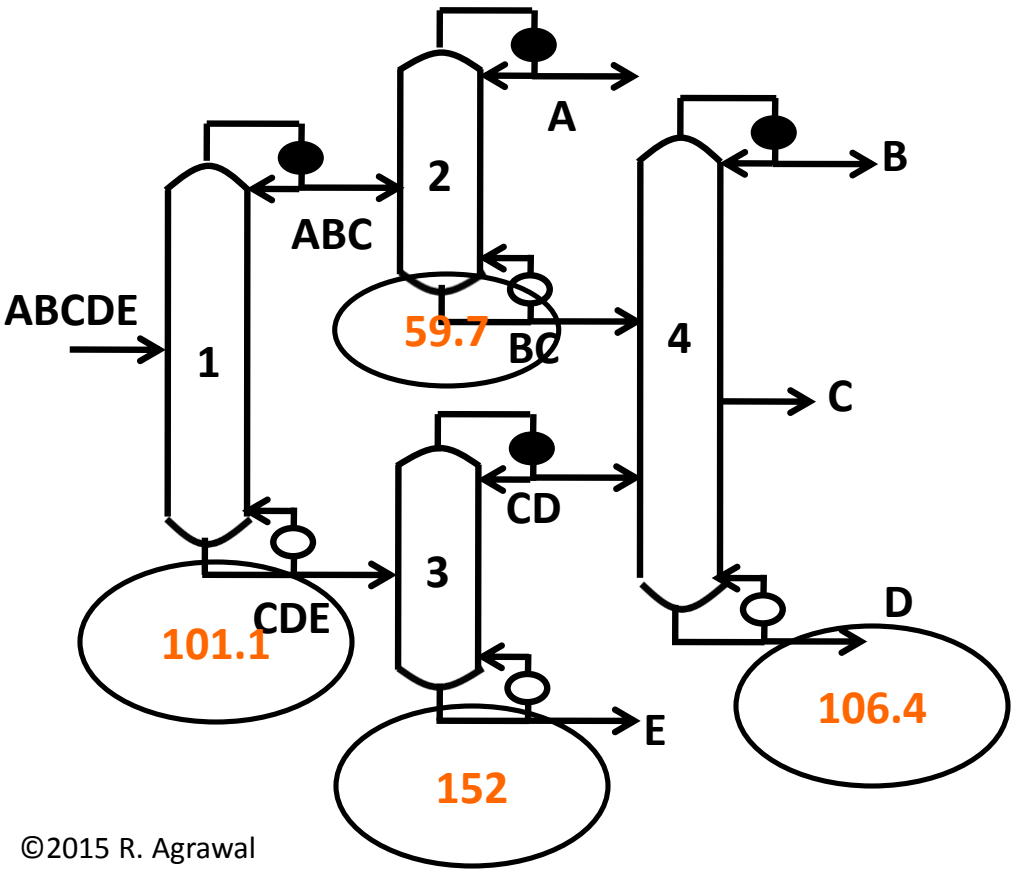

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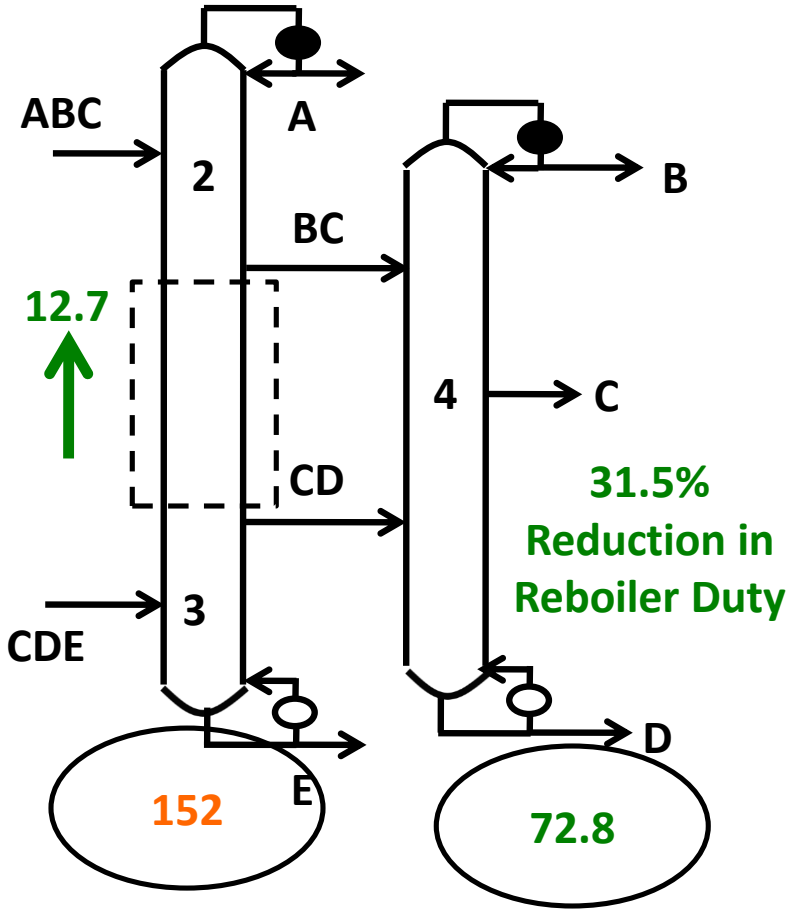

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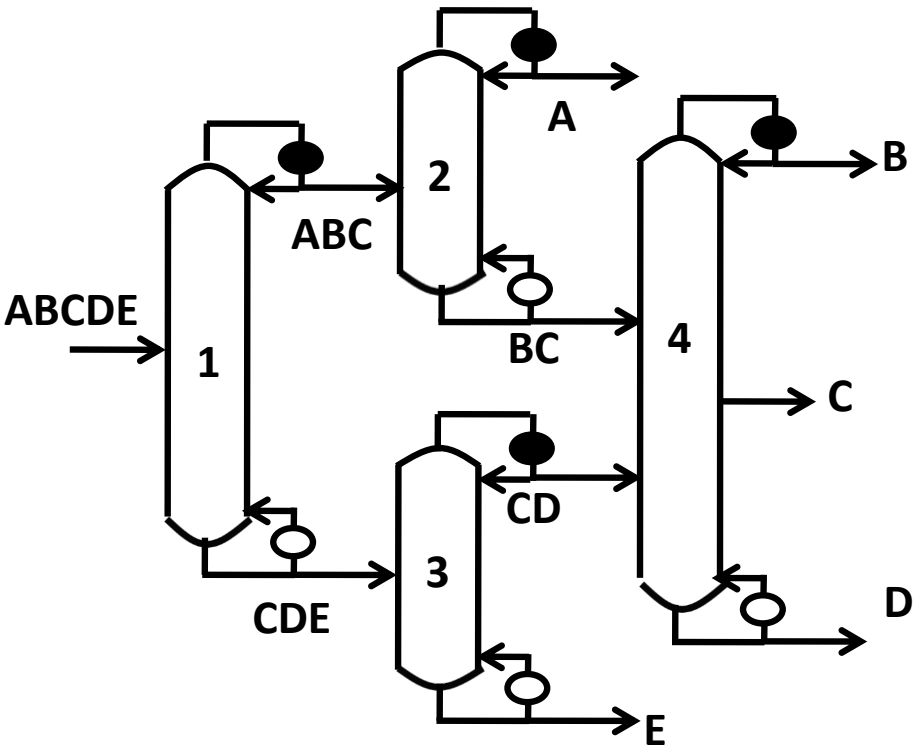

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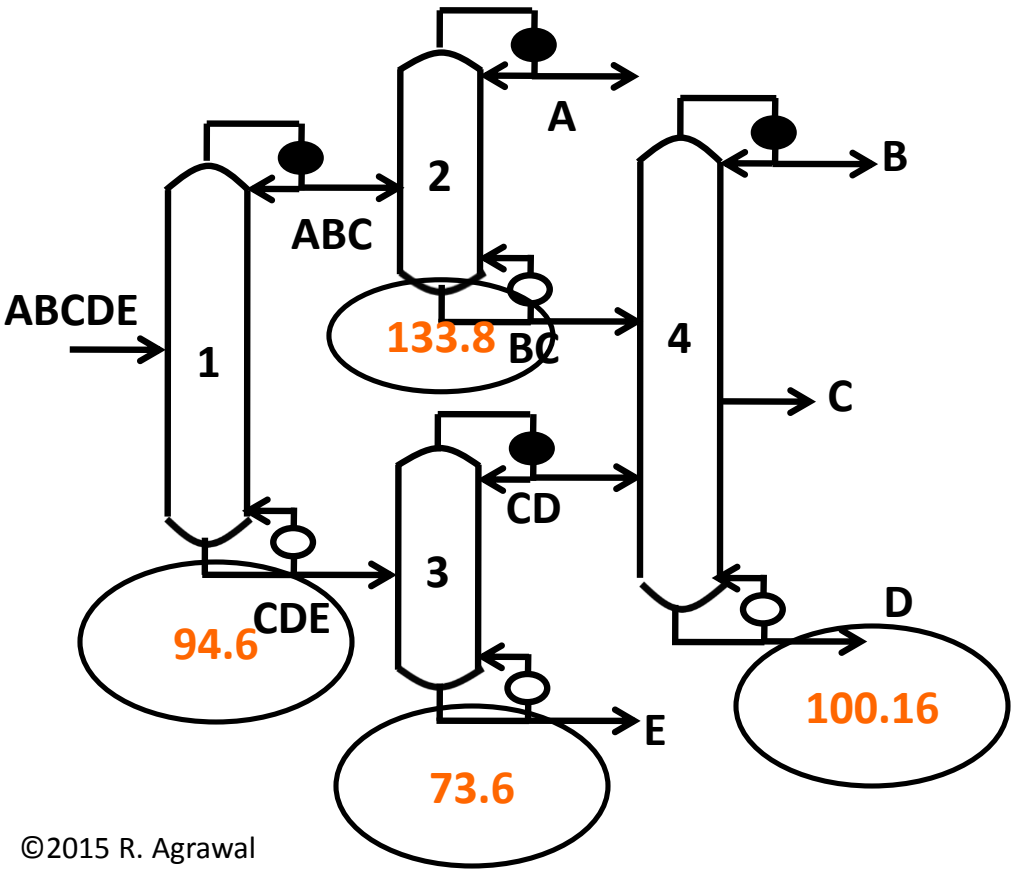

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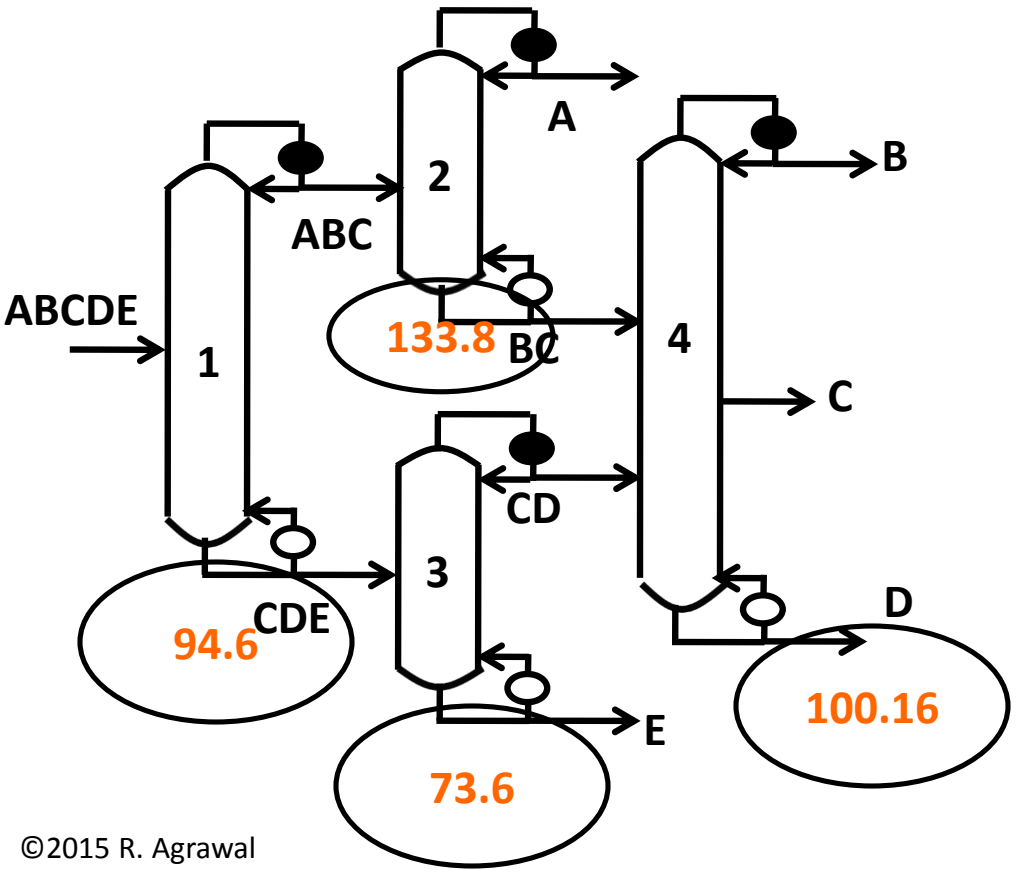
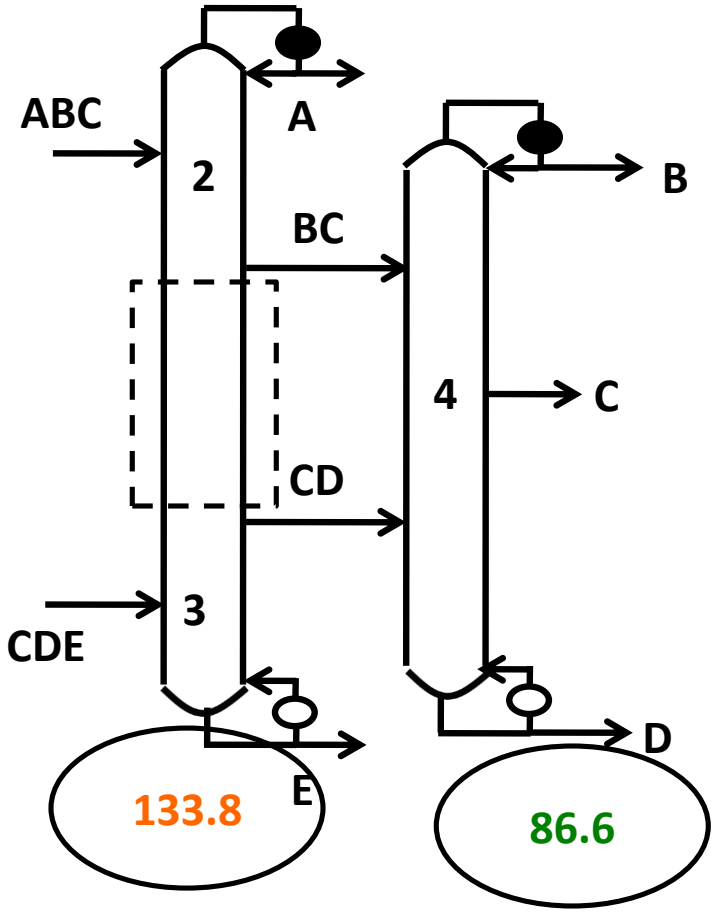


Overall Heat Duty Savings = 21.7%



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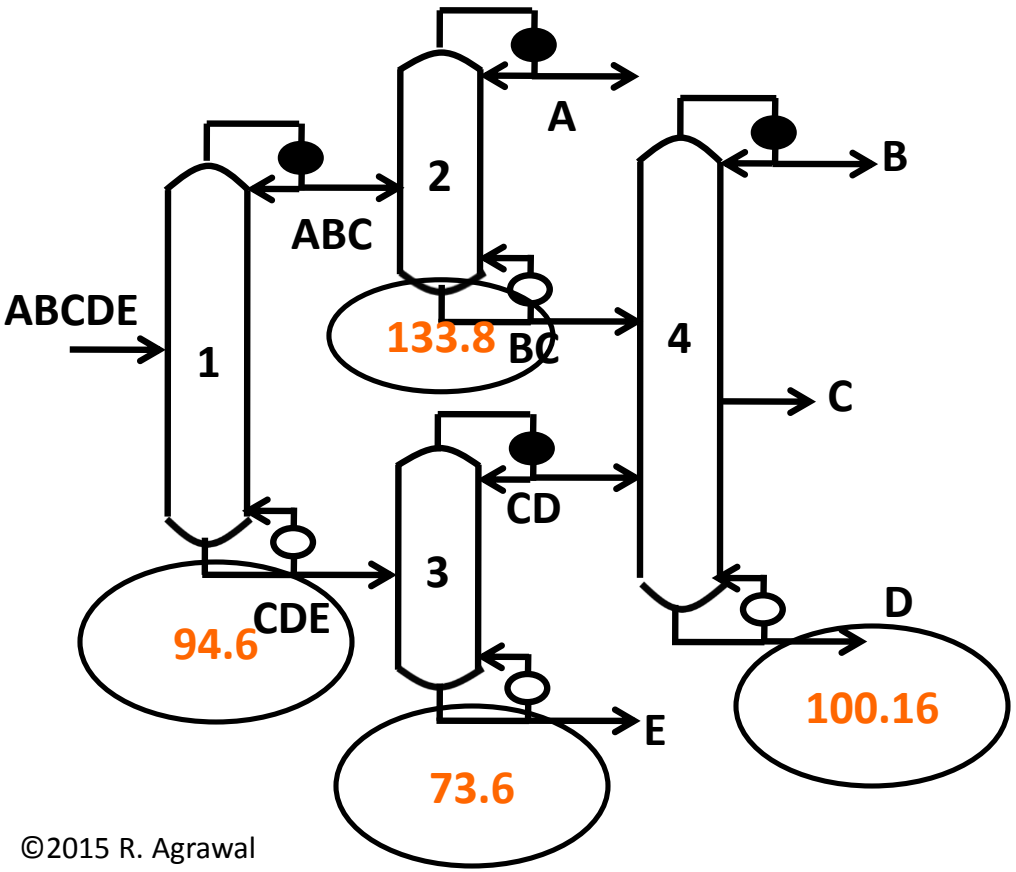

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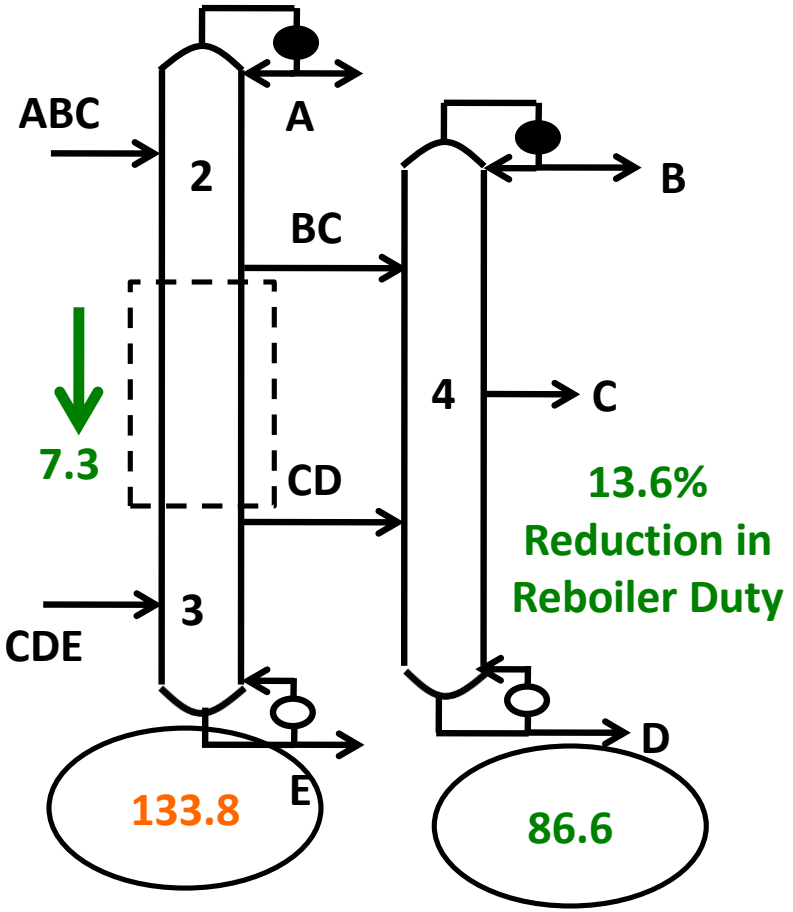


Conclusions

- Introduced a new, general framework for heat and mass integration with additional sections (HMAs)
- HMAs lead to reduction in equipment (distillation columns, reboilers, condensers, connecting streams and valves)
- Studied the operational aspects of HMAs
- Demonstrated the heat duty saving potential of HMAs
- Need to be considered as candidates for cost-evaluation for any given application

Acknowledgements

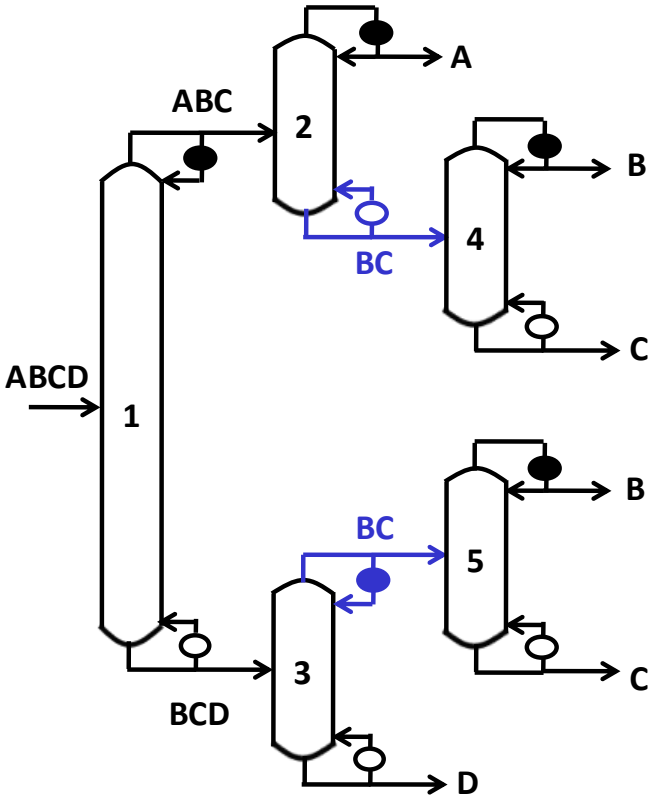
- **DOE, Office of Energy Efficiency and Renewable Energy (Grant#DE-EE0005768)**

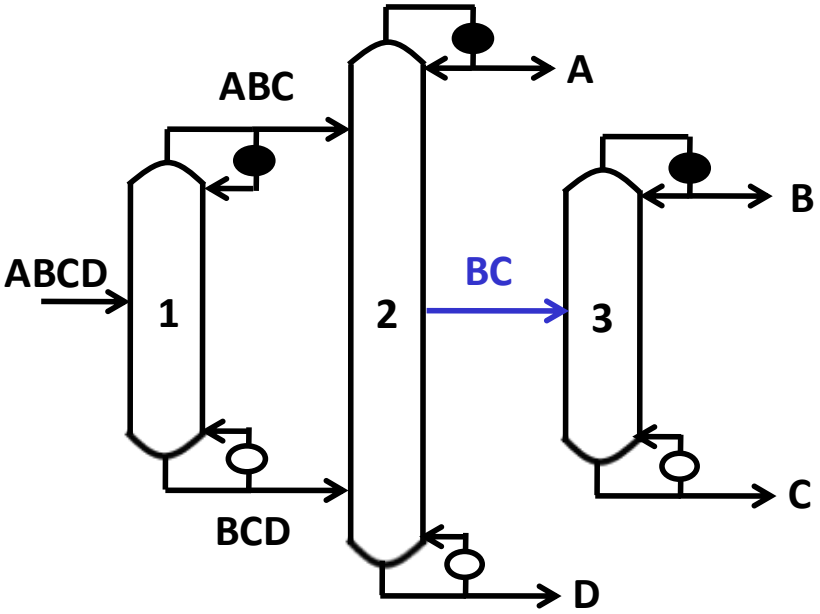
Disclaimer

DOE, Office of Energy Efficiency and Renewable Energy (Grant#DE- EE0005768) The information, data, or work presented herein was funded in part by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.


Thank you

Heat and Mass Integration



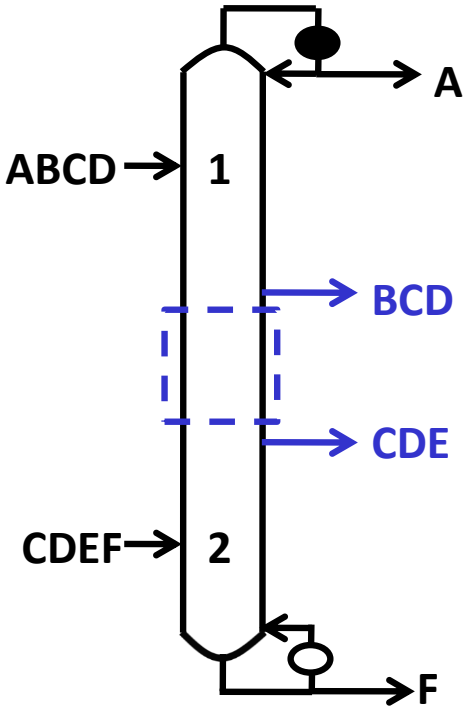


Sargent RWH, Gaminibandara K. 1976; Agrawal R. 1996, 2003

HMA: Two Overlaps

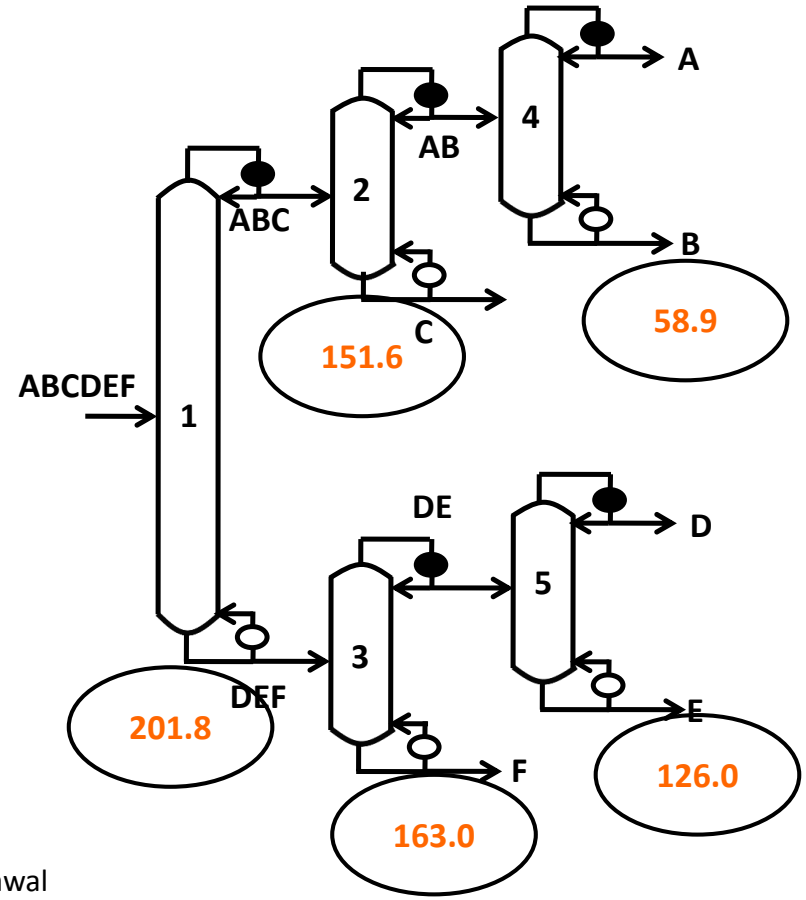
- For $\{\alpha_{BC}, \alpha_{CD}, \alpha_{DE}\} = \{1.1, 1.1, 1.1\}$, at BR=5 (> BR_{min} = 4.46)

BCD Flowrate	*CDE* Flowrate	Net Mass	Net *B*	Net *C*	Net *D*	Net *E*	Direction of component flows
kmol/hr							
88	62	13	0	8.142	4.709	0.150	↑C ↑D ↑E
87	63	12	0	7.819	4.173	0.008	
86	64	11	0	7.471	3.528	0.001	
85	65	10	0	7.121	2.879	0	↑C ↑D
⋮	⋮	⋮	⋮	⋮	⋮	⋮	
81	69	6	0	5.721	0.279	0	
80	70	5	0	5.371	-0.371	0	↑C ↓D
79	71	4	0	5.021	-1.021	0	
⋮	⋮	⋮	⋮	⋮	⋮	⋮	
70	80	-5	0	0.748	-5.748	0	
69	81	-6	0	0.115	-6.114	0	
68	82	-7	0	-0.520	-6.480	0	↓C ↓D
⋮	⋮	⋮	⋮	⋮	⋮	⋮	
64	86	-11	0	-3.059	-7.941	0	
63	87	-12	-0.001	-3.693	-8.306	0	↓B ↓C ↓D
62	88	-13	-0.002	-4.328	-8.671	0	
61	89	-14	-0.005	-4.960	-9.035	0	



Heat Duty Benefits: HMAs With No Overlap

- **Equimolar feed; All transfer streams including feed: liquid phase**
  $\alpha_{AB} = 2.5$
  $\alpha_{BC} = \alpha_{CD} = \alpha_{DE} = \alpha_{EF} = 1.5$



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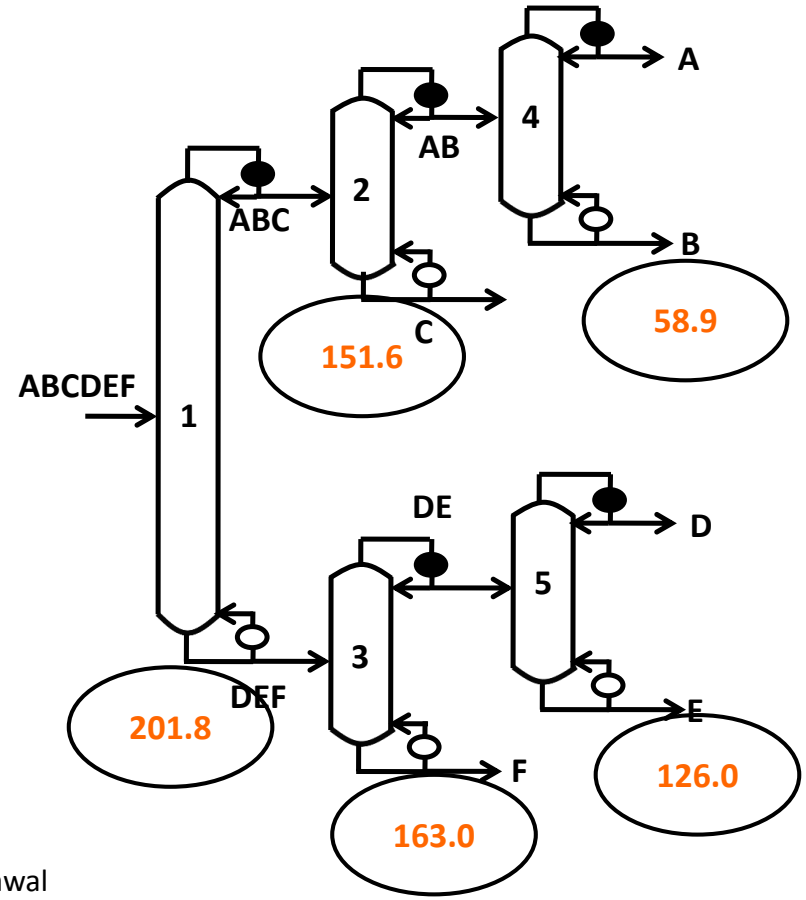

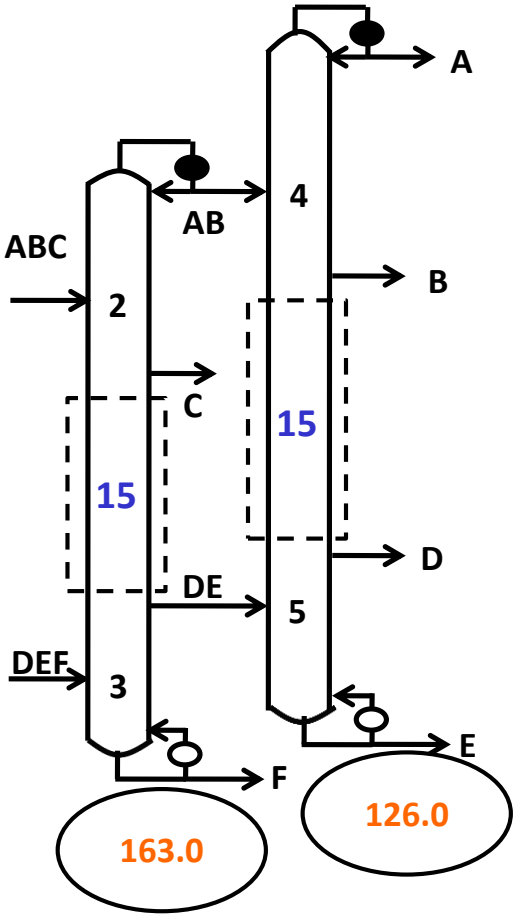

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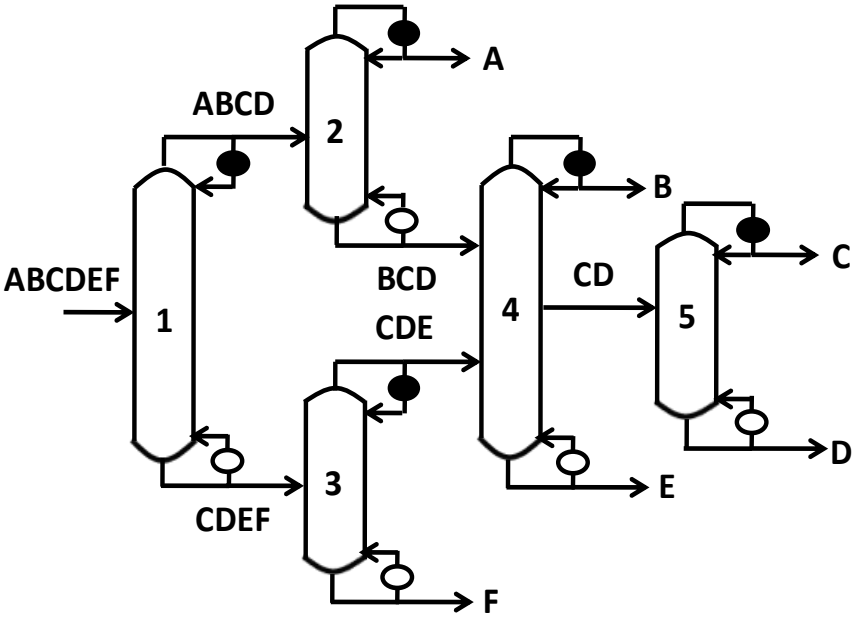
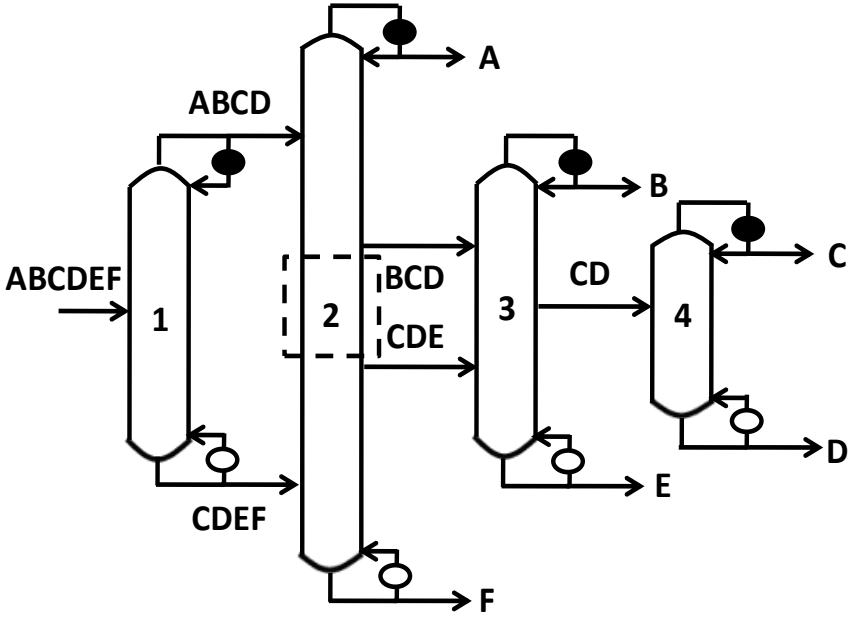
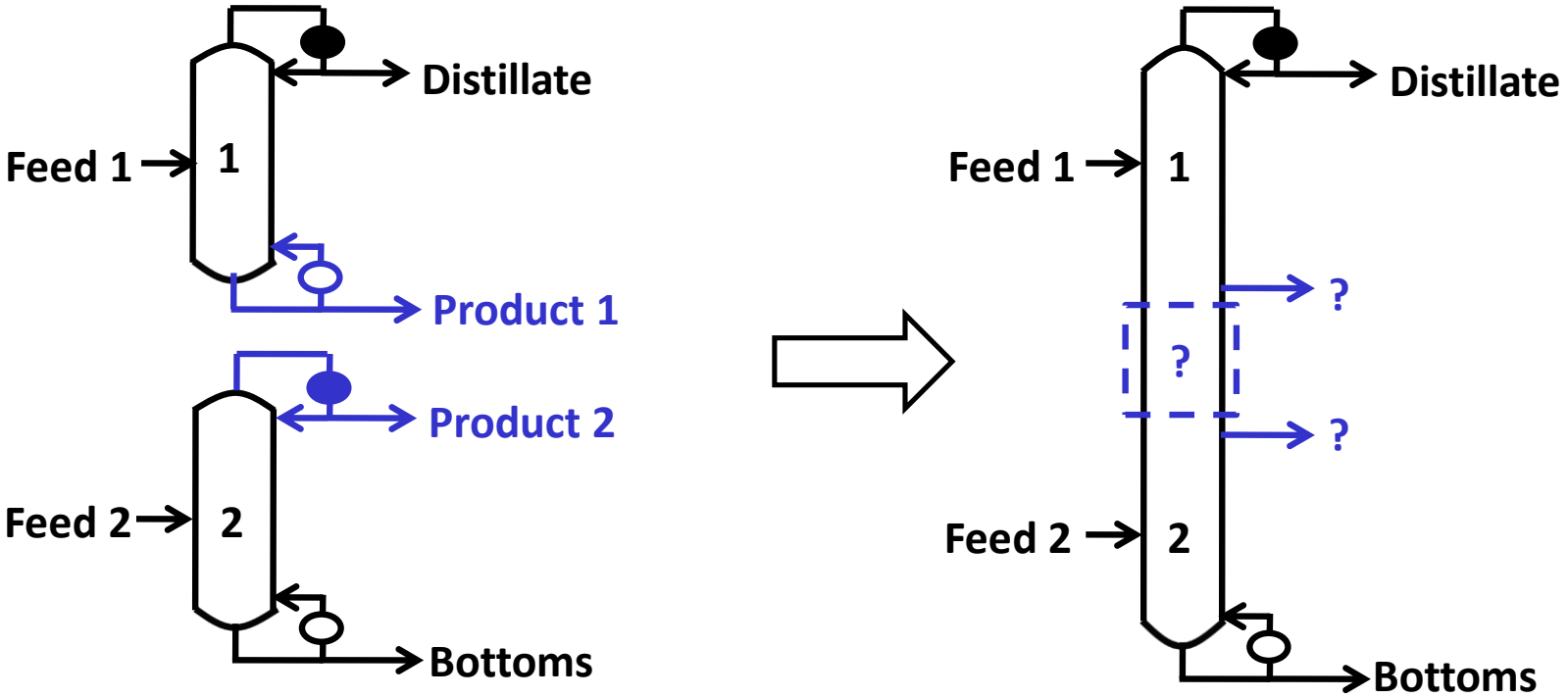




Study of the Operational Aspects of HMAs



- One representative HMA of each category on ASPEN Plus
- Feed 1: Saturated vapor; Feed 2: Saturated liquid
- All withdrawal streams: Saturated liquid
- Each component flow in each feed stream = 25 kmol/hr
- No net mass flow section

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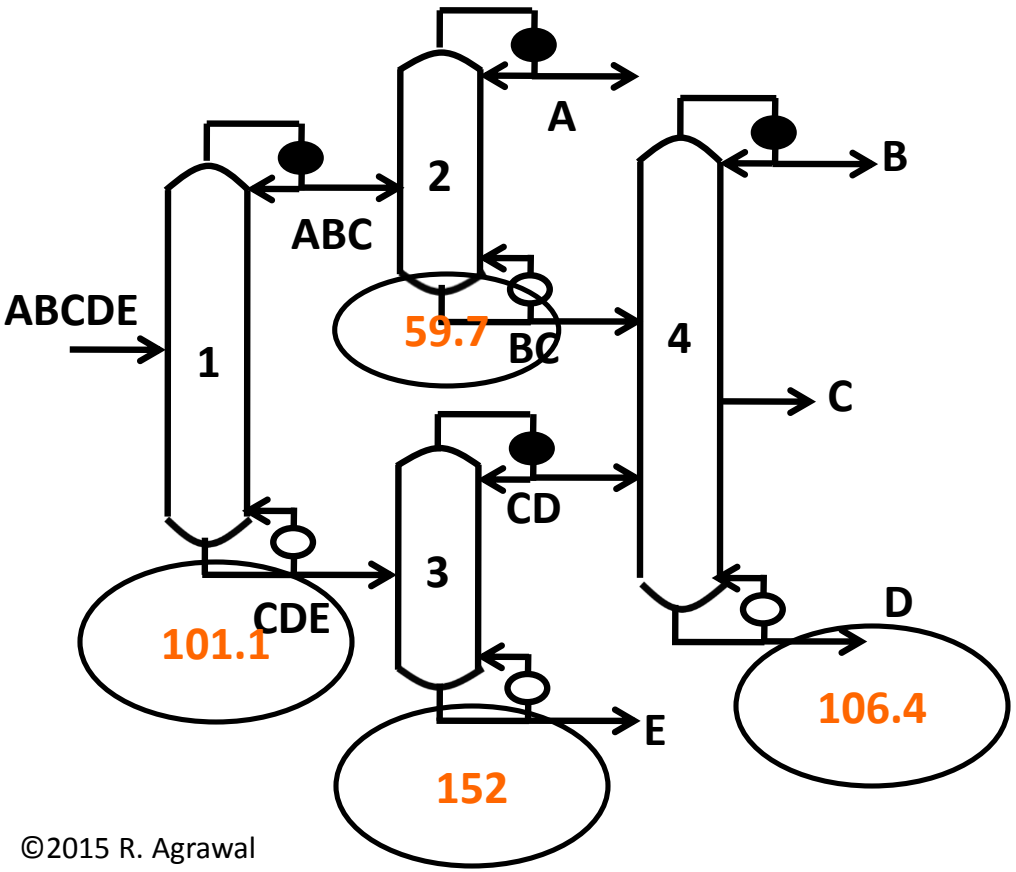

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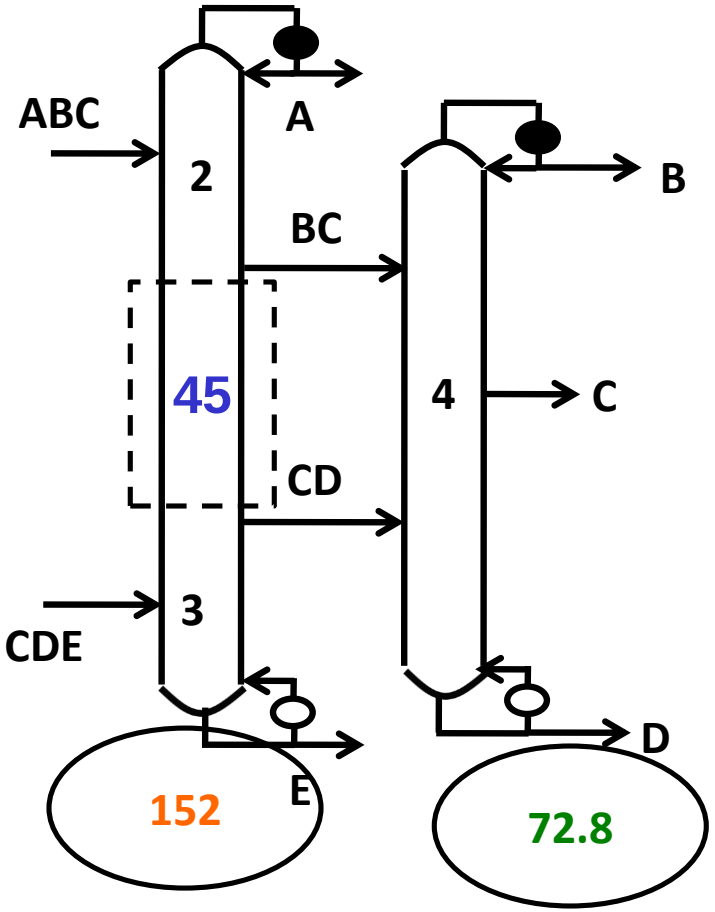

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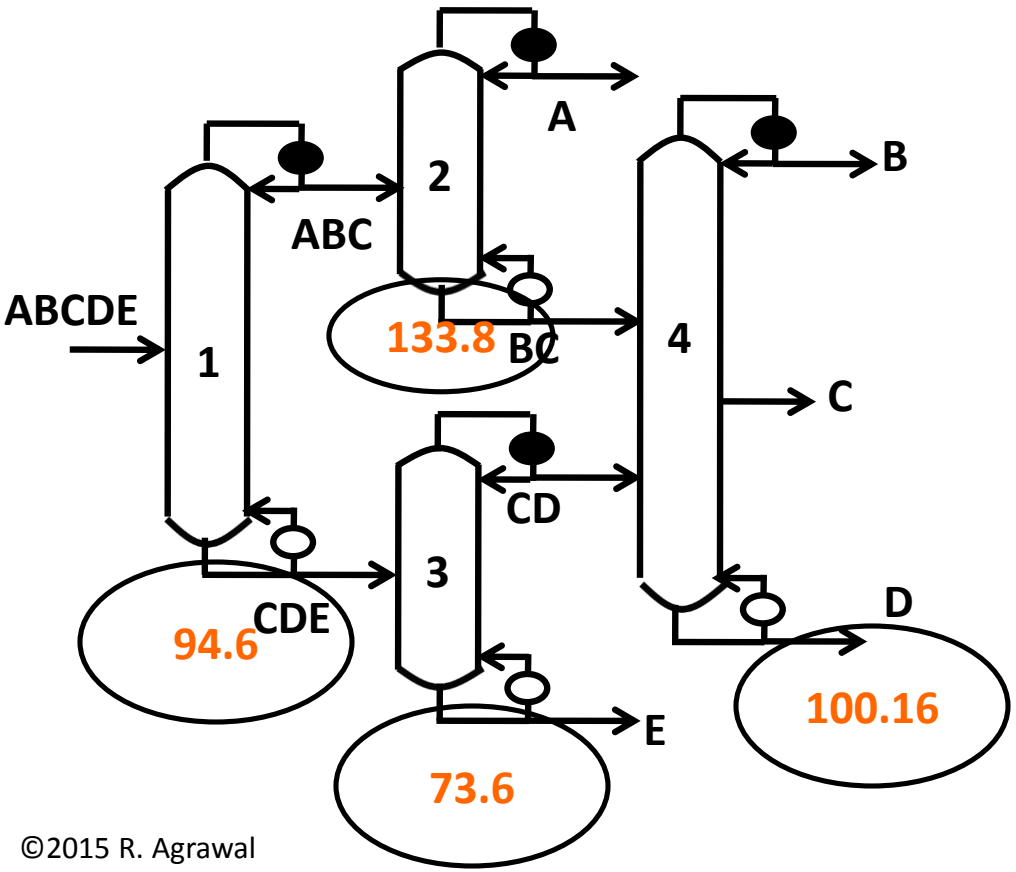

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