Recent improvements to the freeze crystallization method of water purification

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Introduction

- Separation by freezing
- Continuous crystallization
- Batch crystallization
- Optimization
- Capacity
- Applications

Separation methods

Method	Working principle	Key limits
Distillation	Vapor pressure	Energy, maintenance
Adsorption	Surface attraction	Performance
Ion Exchange	Chemical reaction	Regeneration
Reverse Osmosis	Solvent diffusion	Waste, maintenance
Crystallization	Phase solubility	Capacity, waste

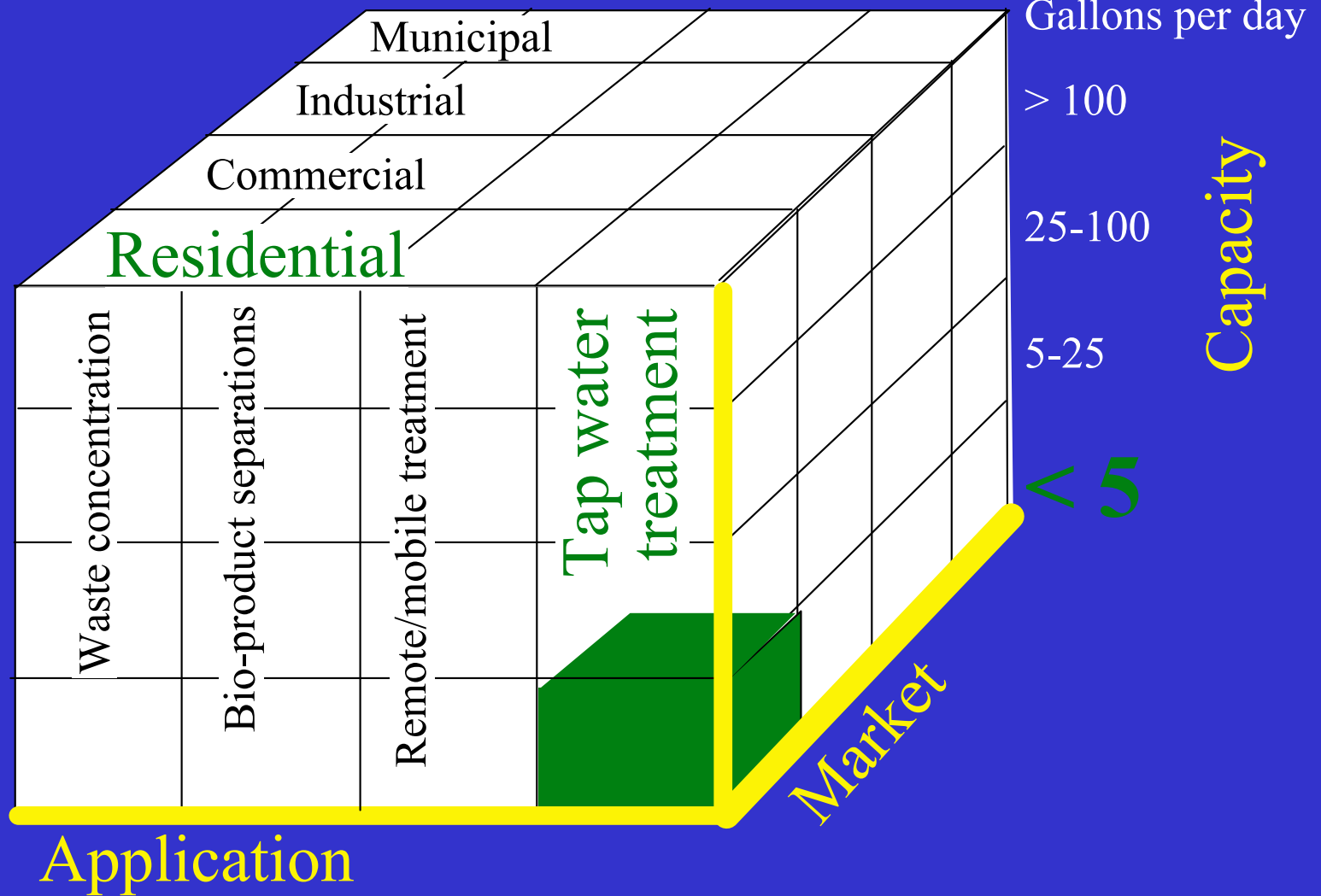
Crystallization advantages

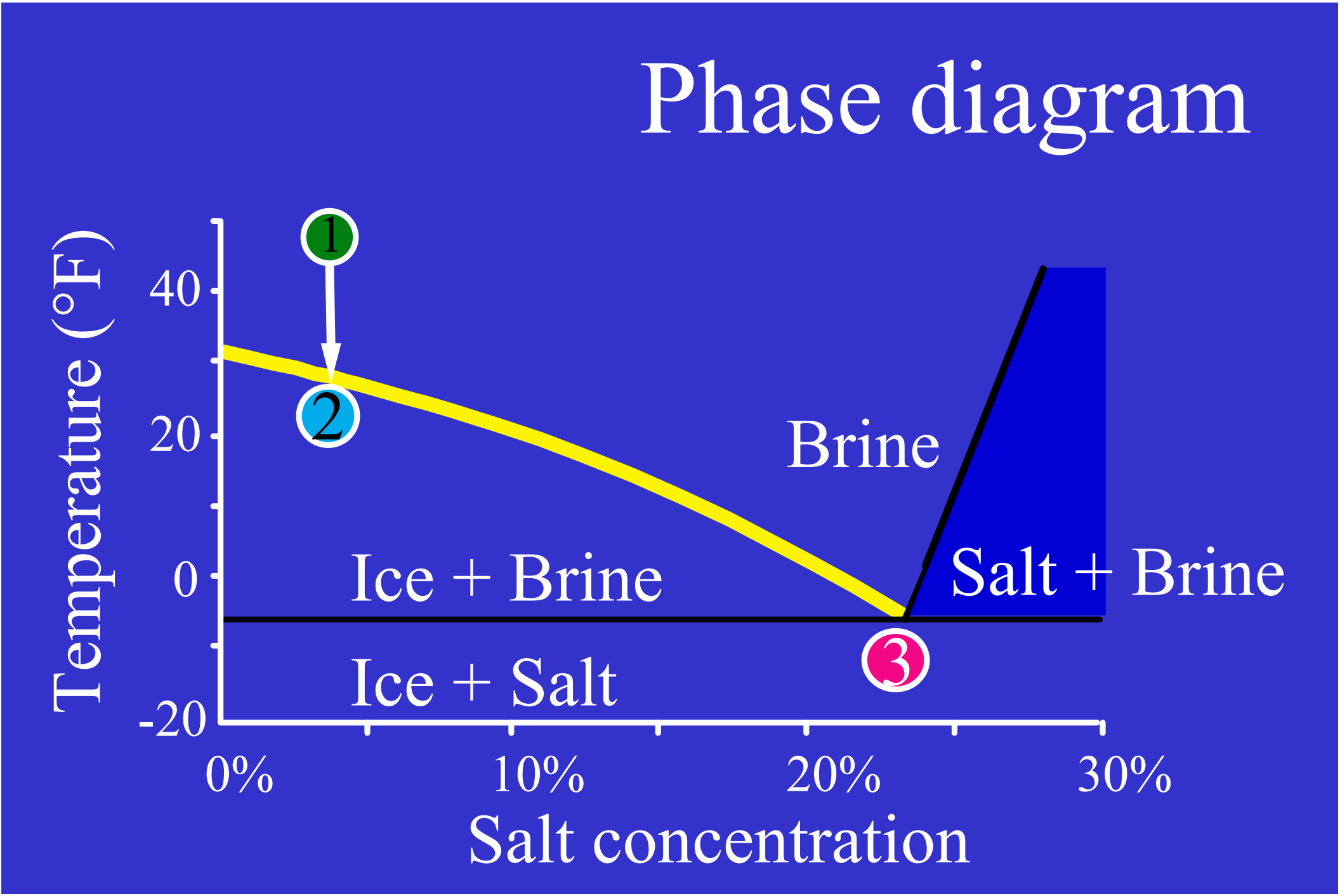
- Highly pure product in one stage
- Broad applicability
- Less energy than distillation
- Higher conversion than RO
- No expendable material

Applications

- Seawater
- Organic chemicals
- Citrus concentrate
- Milk solids
- Silicon refining

Focus


Municipal
Industrial
Commercial
Residential
Waste concentration
Bio-product separations
Remote/mobile treatment
Tap water treatment
Application
Market
Capacity
Gallons per day
> 100
25-100
5-25
< 5


Phase diagram
Temperature (°F)
40
20
0
-20
1
2
3
Brine
Ice + Brine
Salt + Brine
Ice + Salt
0%
10%
20%
30%
Salt concentration

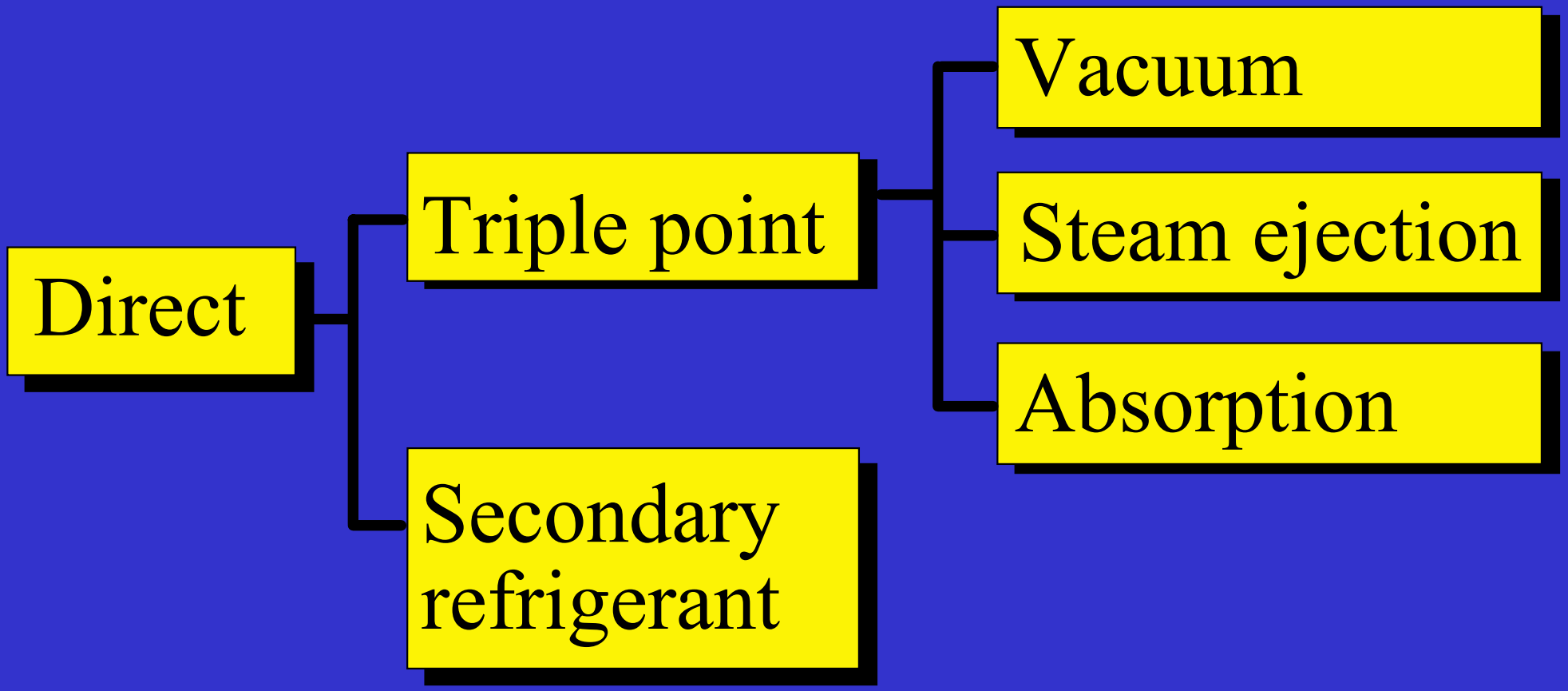
Crystallization

Steps & methods

- Freezing
- Separating
- Melting

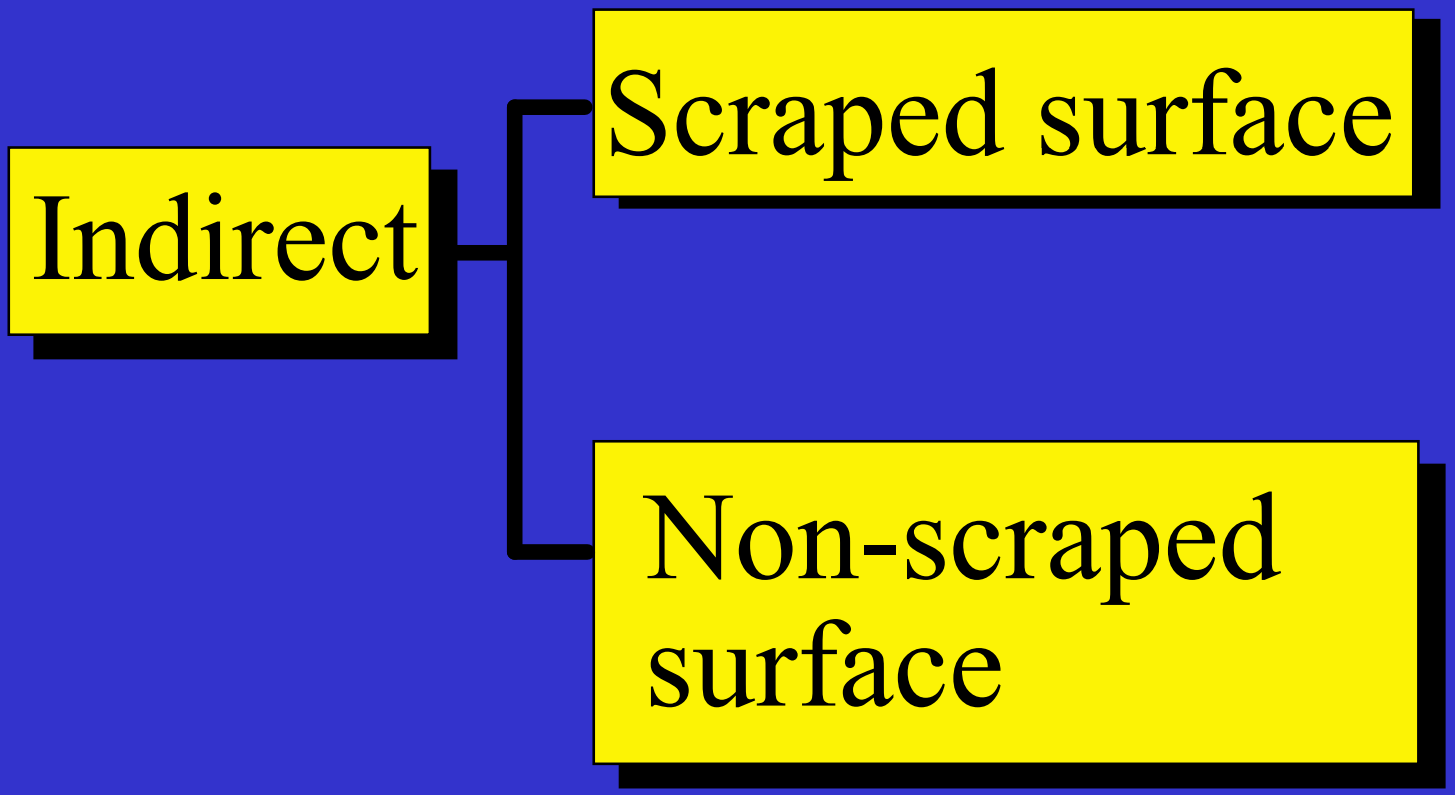
Crystallization

Direct freezing



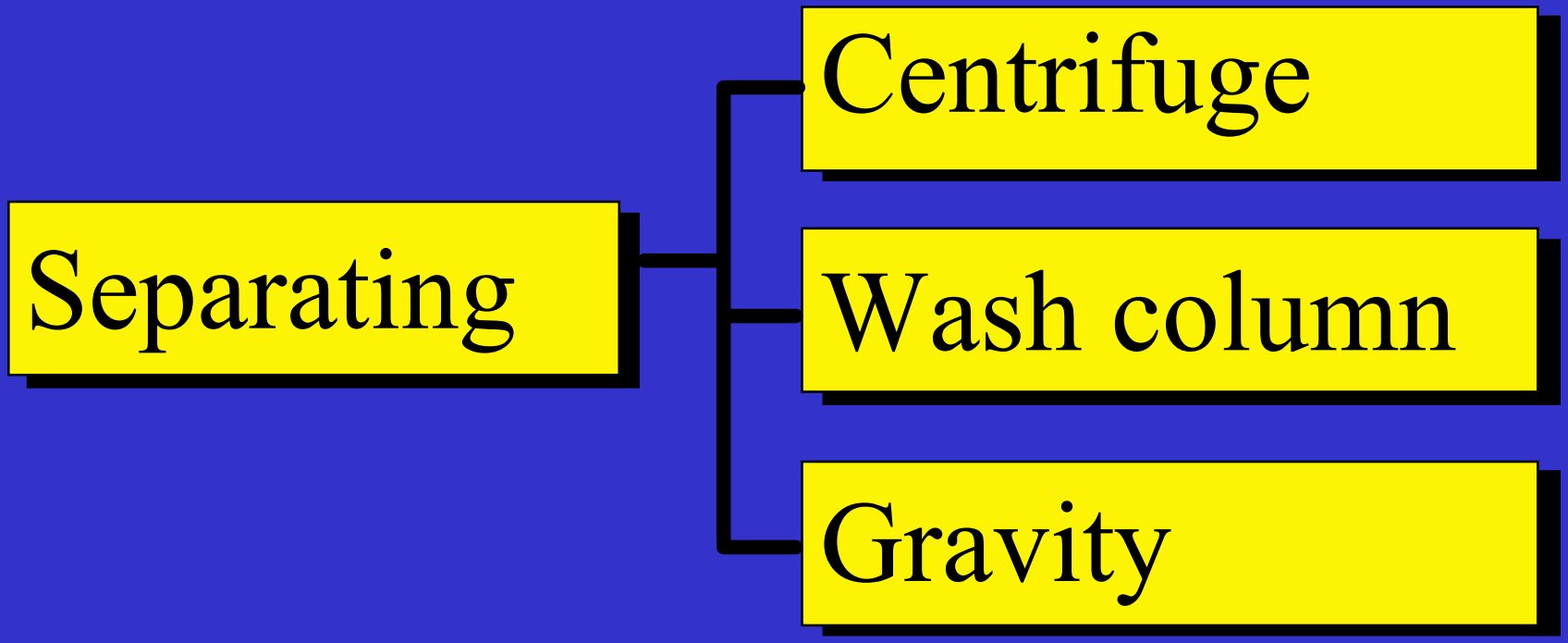
Crystallization

Indirect freezing



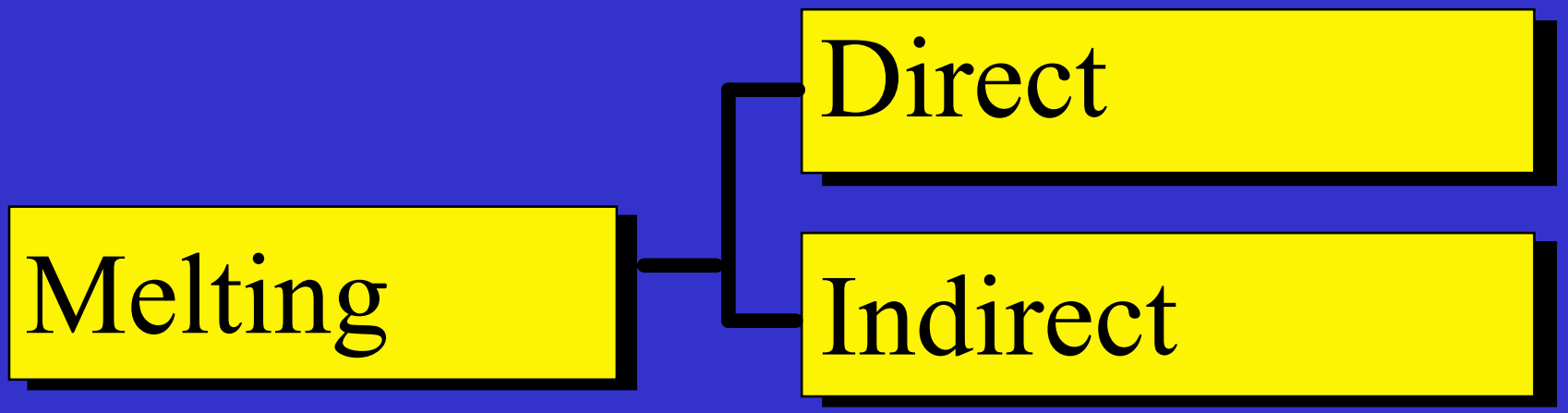
Crystallization

Separating

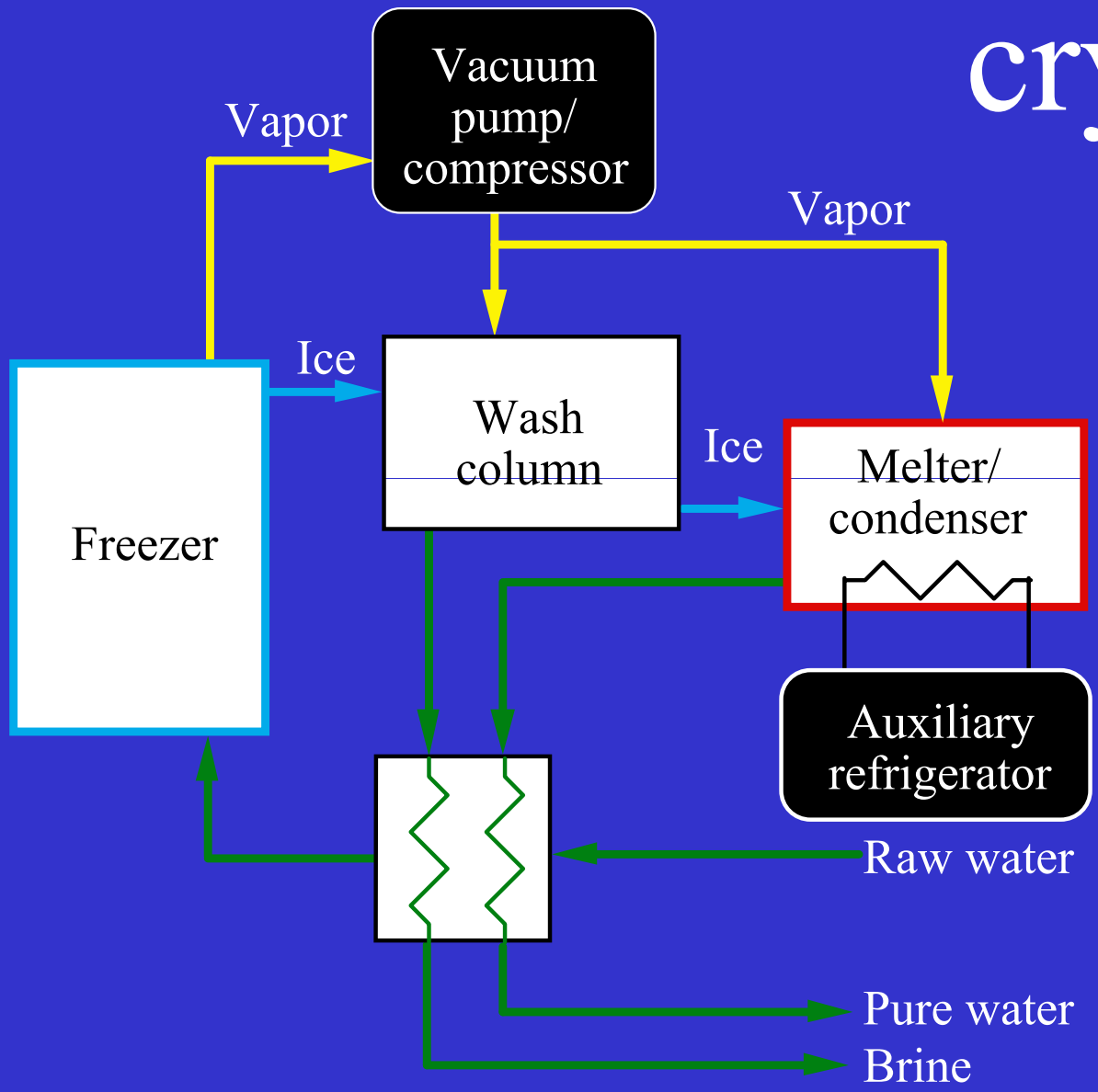


Crystallization

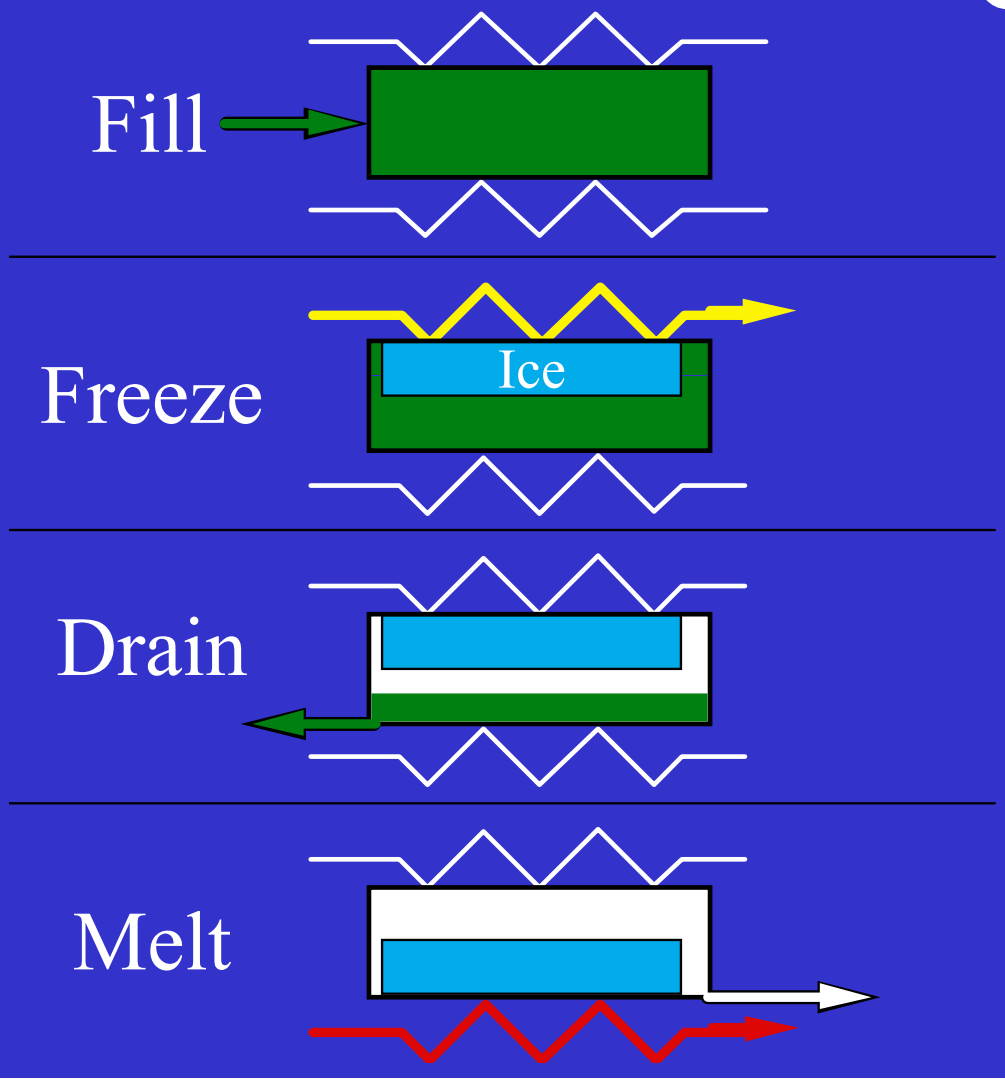
Melting



Continuous crystallizer



Batch crystallizer



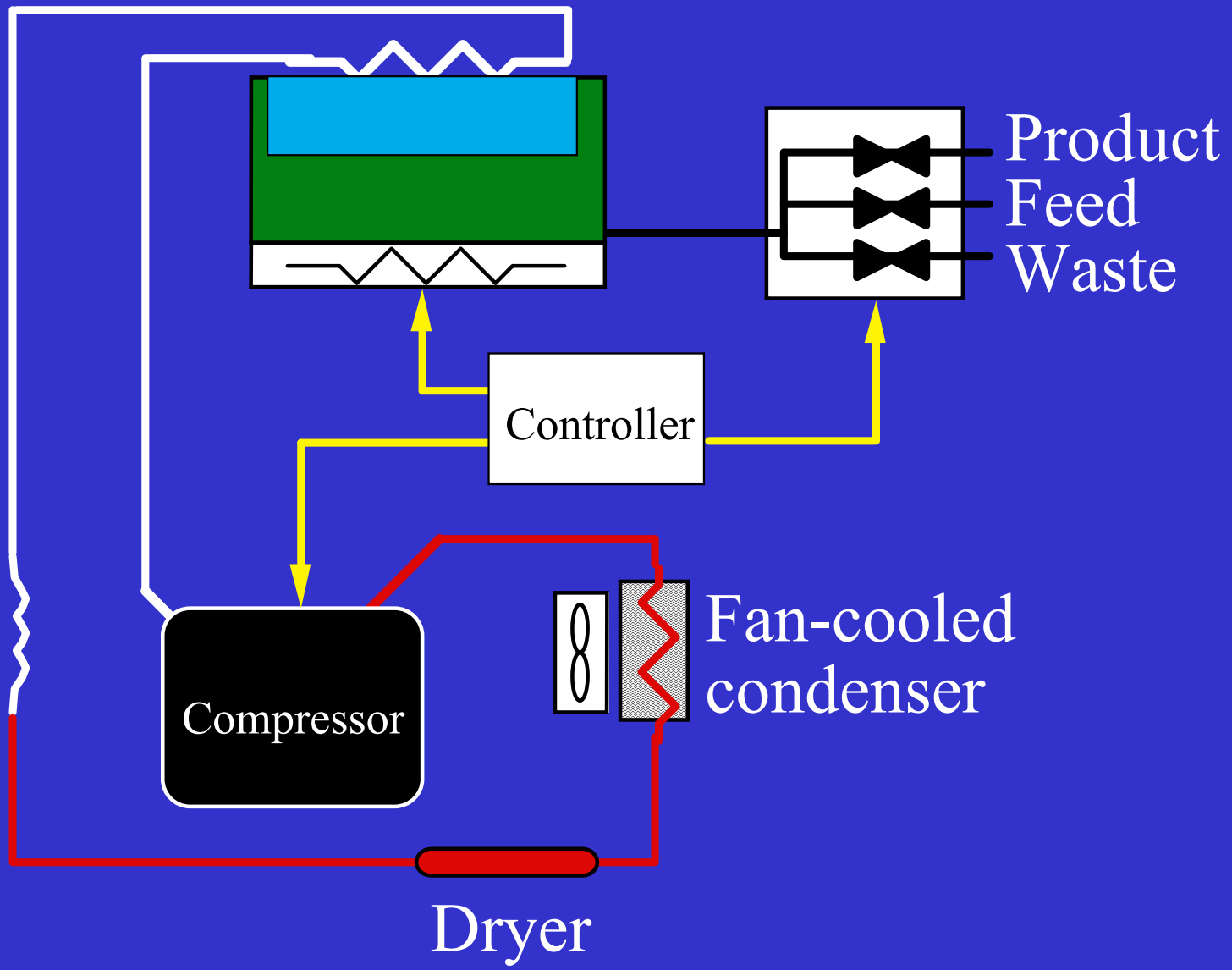
Characteristics

- Batch process
- Indirect freezing
- Large crystal
- Quiescent growth
- No ice transport

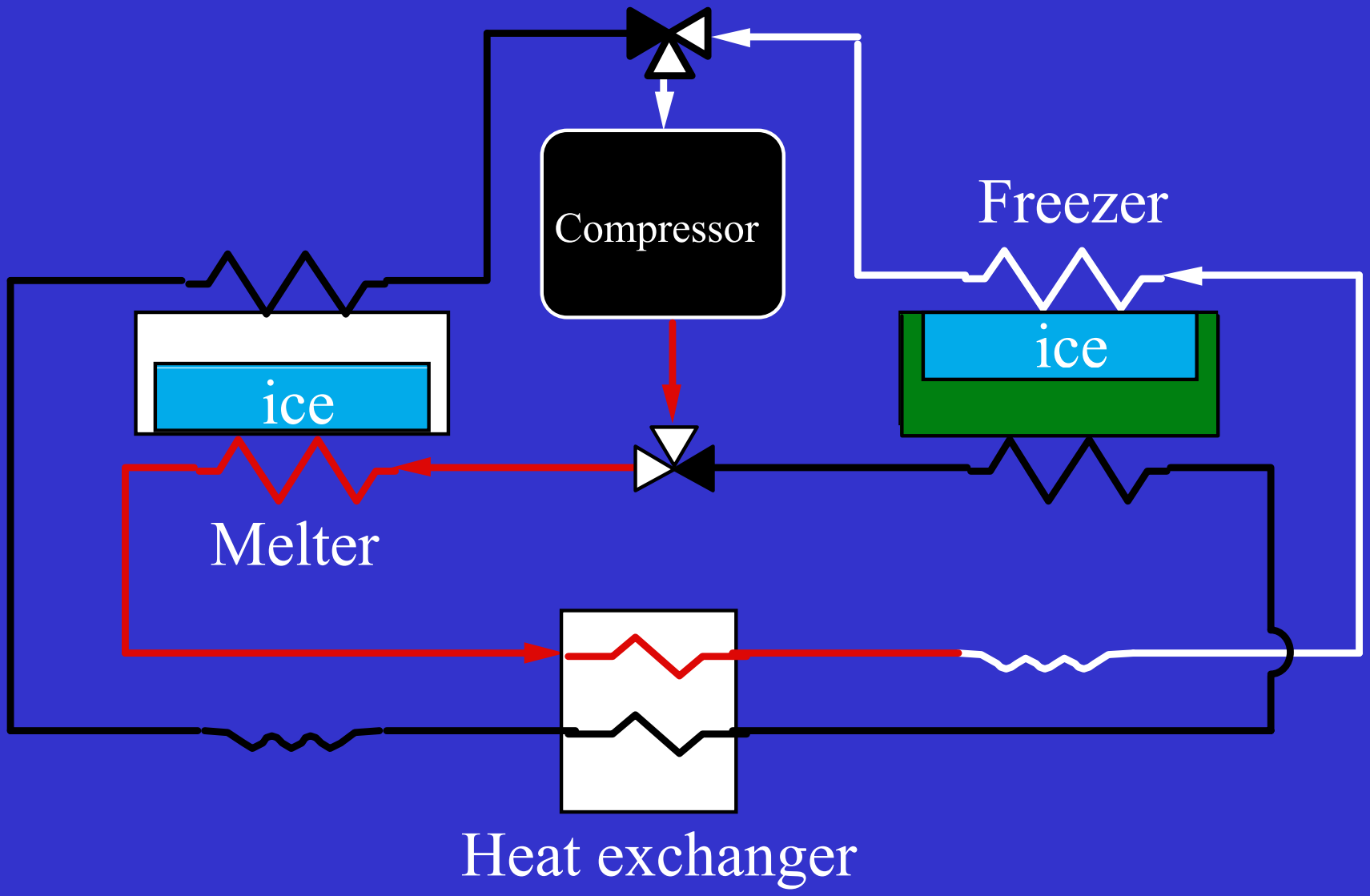
Purification

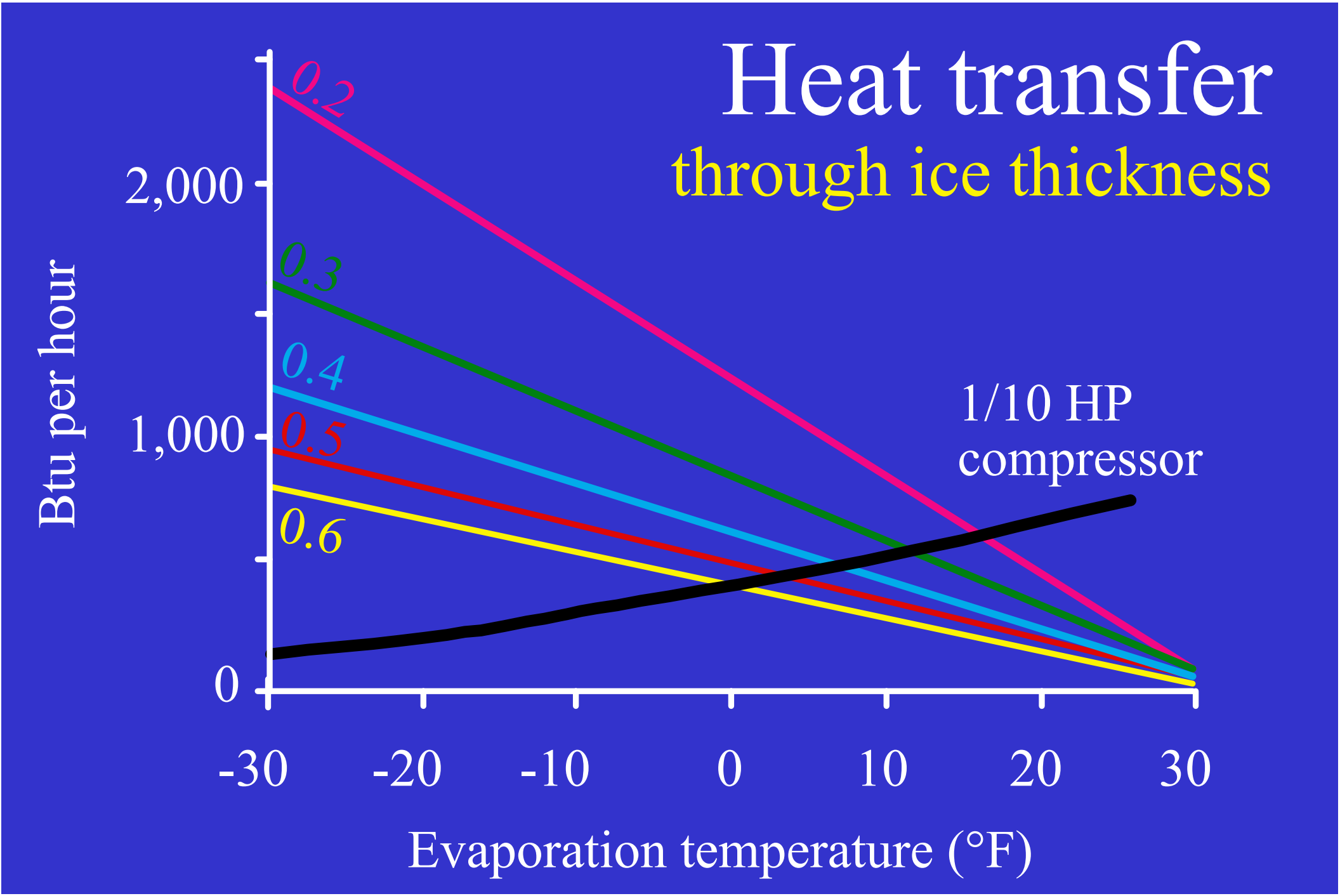
	Contaminant	Source	Product	Rejection
General Minerals	Bicarbonate	120 ppm	6 ppm	95.00%
	Calcium	42 ppm	4 ppm	90.50%
	Chloride	26 ppm	0.95 ppm	96.30%
	Magnesium	15 ppm	2.7 ppm	82.00%
	Sodium	17 ppm	0.65 ppm	96.20%
	Sulfate	13 ppm	0.62 ppm	95.20%
Harmful Minerals	Nitrate	190 ppm	0.66 ppm	99.65%
	Lead	190 ppm	0.88 ppm	99.54%
	Lead	82 ppb	Not Detected	100%
	Lead	55 ppb	Not Detected	100%
	Lead	49 ppb	Not Detected	100%
Organic Chemicals	Chloroform	34.188 ppb	0.094 ppb	99.73%
	$BrCl_2$ Methane	8.029 ppb	0.005 ppb	99.94%
	Br_2Cl Methane	15.418 ppb	0.0025 ppb	99.98%
	Bromoform	11.28 ppb	0.0 ppb	100.00%
Bacteria	E.coli			100%

Implementation



Dual chamber

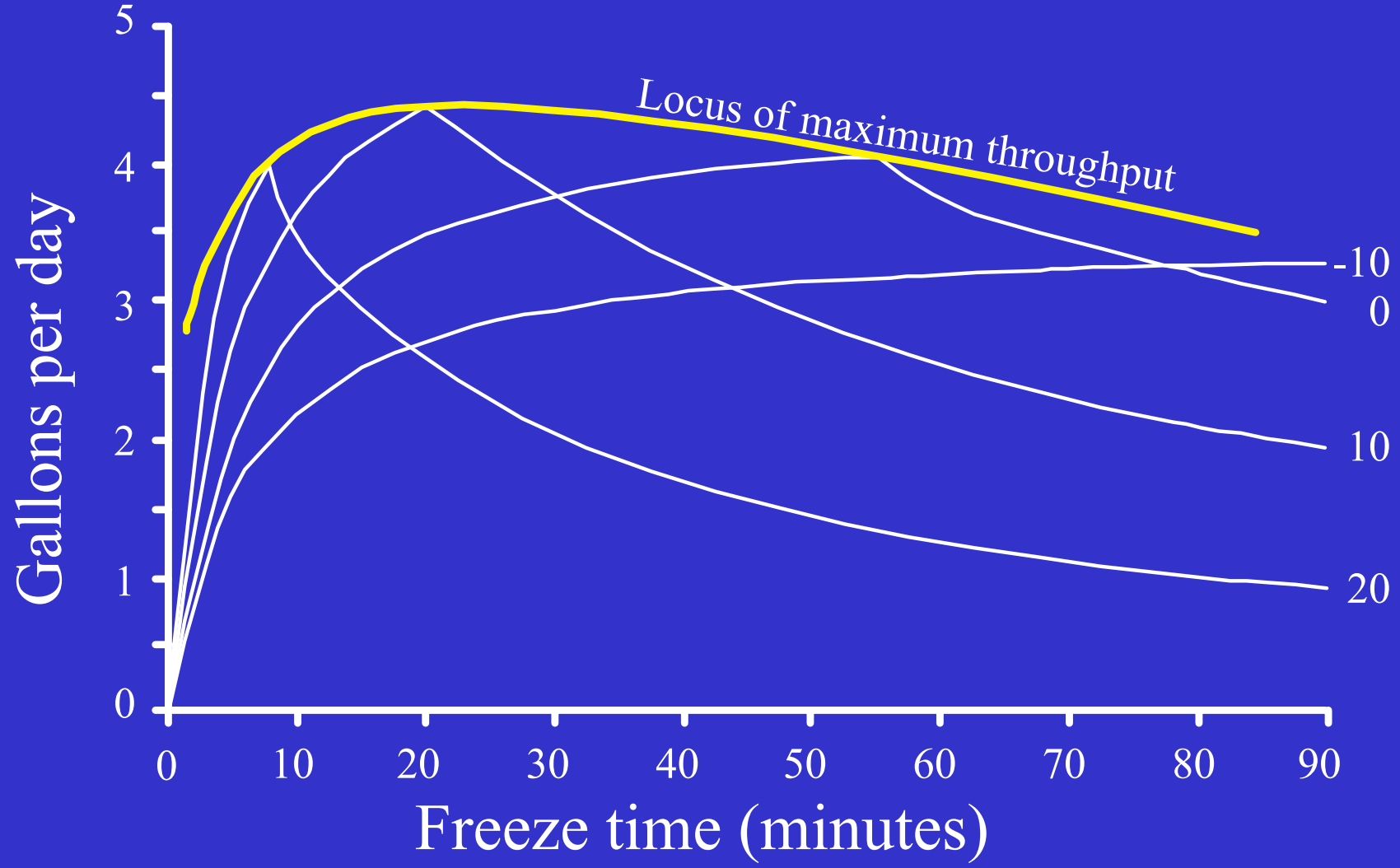



Heat transfer
through ice thickness
0.2
0.3
0.4
0.5
0.6
1/10 HP
compressor
2,000
1,000
0
Btu per hour
-30
-20
-10
0
10
20
30
Evaporation temperature (°F)

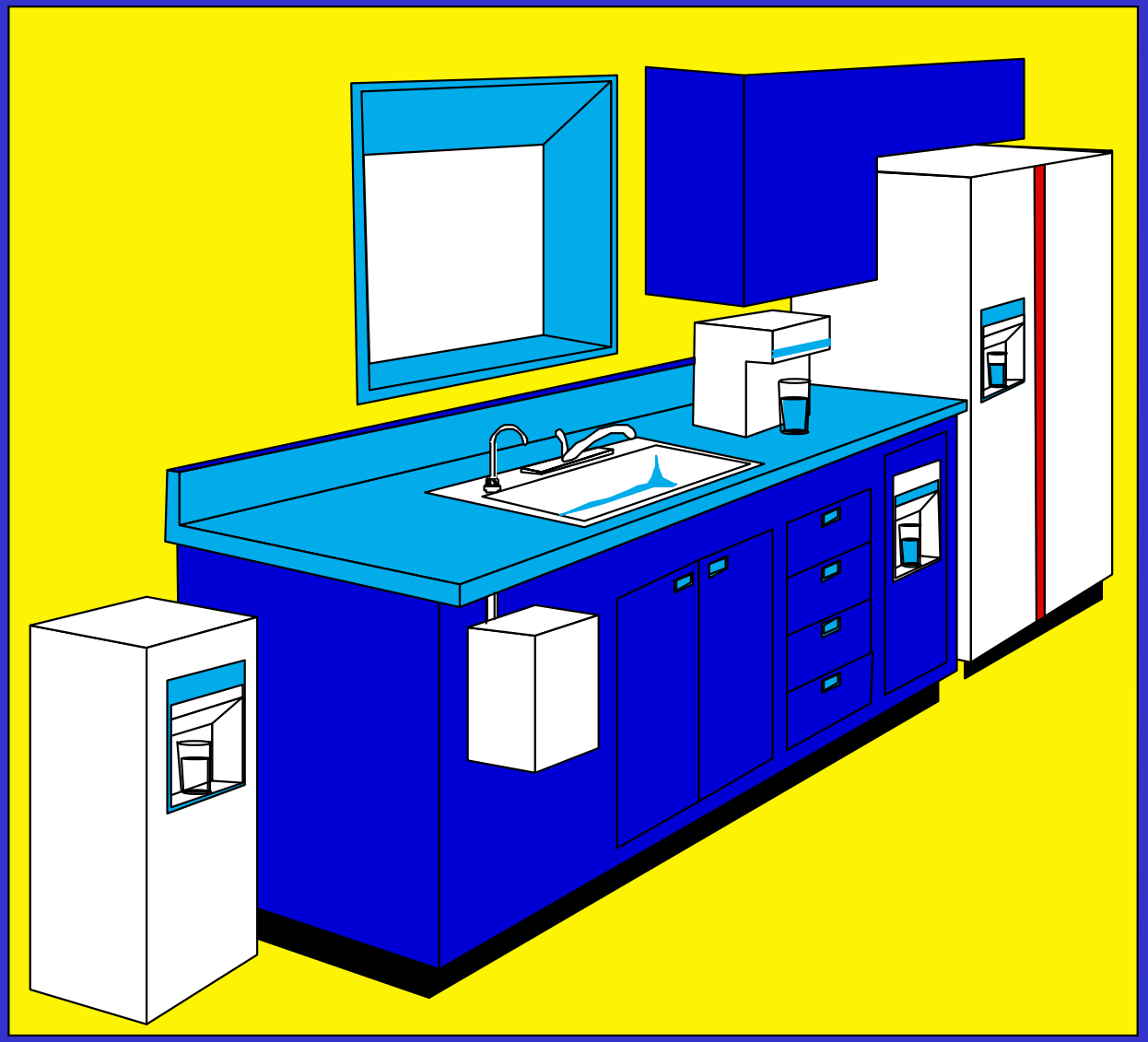
Capacity
Factors

- Conversion
- Compressor capacity
- Feedwater temperature
- Melter capacity
- Overhead time

Capacity
Optimization



Appliance options



- Countertop
- Under sink
- Built-in
- Cooler
- Refrigerator

Conclusion

- Batch process
- Effective separation
- Simple implementation
- Optimized
- No expendables
- Chilled drinking water