Ammonia by Design

Evaluate changes that increase product at equilibrium

HS-PS1-6 "Evaluate the design of a chemical system by changing conditions to produce increased amounts of products at equilibrium, and refine the design, as needed."

NAME _____ DATE _____

1 READ AND MARK

Read it twice

YOUR JOB Underline each change the engineers test or propose, circle evidence about its effect on ammonia at equilibrium, and number the costs or speed limits they must consider.

A Fertilizer Plant's Balancing Act

1. At a fertilizer plant, engineers feed nitrogen and hydrogen into a sealed reactor to make ammonia: $N_2 + 3H_2 \rightleftharpoons 2NH_3$. The forward reaction releases heat. Inside the reactor, ammonia molecules also break apart, so both reactions continue after the mixture reaches equilibrium. The engineers want more ammonia from each pass, but they also need a process that runs quickly and safely. In a trial at 400 °C and 150 atmospheres of pressure, 18% of the starting nitrogen has become ammonia at equilibrium. This result gives the team a starting design to improve.

2. The team tests one change at a time. At 250 atmospheres and 400 °C, the equilibrium mixture contains ammonia made from 25% of the starting nitrogen. Higher pressure favors the side with fewer gas molecules: two ammonia molecules rather than four reactant molecules. But compression uses more electricity, and stronger equipment costs more. In another test, the team lowers the temperature to 350 °C while keeping pressure at 150 atmospheres. Conversion at equilibrium rises to 23%, since lower temperature favors the heat-releasing direction. However, the reaction takes longer to approach equilibrium at the lower temperature.

3. A catalyst helps the mixture approach equilibrium faster by speeding both the forward and reverse reactions. It does not change the equilibrium conversion at a fixed temperature and pressure. After the reactor, a cooler turns much of the ammonia into liquid that can be removed. The leftover nitrogen and hydrogen return to the reactor. Removing ammonia between passes favors formation of more ammonia as the returned gases approach a new equilibrium. The team considers moderate heating, a catalyst, and recycled gases, then weighs extra ammonia against electricity use, equipment cost, and production time before deciding whether higher pressure is worth it.

2 ANSWER WITH EVIDENCE

Use the passage

1. Would the higher-pressure trial improve the team's starting design? Use the trial results and one tradeoff to explain your judgment.

2. How does lowering the temperature change the design's performance at 150 atmospheres? Explain both the benefit and the drawback.

3. An engineer suggests adding only a catalyst to increase the amount of ammonia at equilibrium. Evaluate that suggestion.

4. Suppose the plant cannot buy a stronger pressure vessel. Which two changes from the passage could increase ammonia production without raising pressure, and what limitation should the team plan for?

3 YOUR TURN

Your own words

A second plant makes sulfur trioxide: $2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g) + \text{heat}$. Propose two condition changes that would increase product at equilibrium, explain each using the equation, and refine your design to address one cost or speed tradeoff.

Ammonia by Design

PART 1 · READ AND MARK

Underline each change the engineers test or propose, circle evidence about its effect on ammonia at equilibrium, and number the costs or speed limits they must consider. Accept any marking that follows this job and points at the right text.

PART 2 · ANSWERS

#	QUESTION	ANSWER
1	Would the higher-pressure trial improve the team's starting design? Use the trial results and one tradeoff to explain your judgment.	**Yes, equilibrium conversion rises from 18% to 25%, but compression uses more electricity and requires stronger, costlier equipment.**
2	How does lowering the temperature change the design's performance at 150 atmospheres? Explain both the benefit and the drawback.	**Lowering temperature from 400 °C to 350 °C raises equilibrium conversion from 18% to 23%, but the mixture takes longer to approach equilibrium.**
3	An engineer suggests adding only a catalyst to increase the amount of ammonia at equilibrium. Evaluate that suggestion.	**A catalyst speeds the approach to equilibrium, but it does not increase the equilibrium amount of ammonia at a fixed temperature and pressure.**
4	Suppose the plant cannot buy a stronger pressure vessel. Which two changes from the passage could increase ammonia production without raising pressure, and what limitation should the team plan for?	**Lower the temperature and remove liquid ammonia between passes while recycling the leftover gases. Lower temperature increases equilibrium conversion but slows the approach to equilibrium.**

PART 3 · YOUR TURN (SAMPLE ANSWER)

I would raise pressure because the product side has two gas molecules instead of three, so equilibrium would favor SO_3. I would lower temperature because making SO_3 releases heat, so cooling favors the forward reaction. To offset the slower approach to equilibrium at a lower temperature, I would add a catalyst, while checking whether the added product justifies the cost of compression.

Accept other sound refinements, such as limiting the pressure increase to control equipment costs. A catalyst may address reaction speed, but it must not be described as changing the equilibrium amount.