Solution

(a) Instantaneous Selectivity $S_{D/U}$

Reactions:

$$\text{Desired:} \quad A + B \xrightarrow{k_1} D, \quad k_1 = 150 \exp\left(-\frac{5000}{T}\right)$$

$$\text{Undesired:} \quad B \xrightarrow{k_2} 2U, \quad r_U = k_2 C_B^2, \quad k_2 = 300 \exp\left(-\frac{2000}{T}\right)$$

For the desired product D:

$$r_D = k_1 C_A C_B$$

For the undesired product U:

$$r_U = k_2 C_B^2$$

The instantaneous selectivity is:

$$S_{D/U} \equiv \frac{r_D}{r_U} = \frac{k_1 C_A C_B}{k_2 C_B^2} = \frac{k_1}{k_2} \cdot \frac{C_A}{C_B}$$

Substituting the Arrhenius forms:

$$\frac{k_1}{k_2} = \frac{150\, e^{-5000/T}}{300\, e^{-2000/T}} = \frac{1}{2} e^{-3000/T}$$

Thus:

$$\boxed{S_{D/U} = \frac{1}{2} e^{-3000/T} \cdot \frac{C_A}{C_B}}$$

Interpretation: Higher T increases $S_{D/U}$ since the desired step has higher activation energy. Large C_A and low C_B also improve selectivity.

(b) Reactor Systems and Operating Conditions

1. Semibatch Reactor (Charge A, Feed B Slowly)

- **Schematic:** Agitated tank with temperature control; charge with excess A at $t = 0$, feed B continuously.
- **Rationale:** $r_U \propto C_B^2$, so keeping C_B low suppresses the undesired second-order pathway while $r_D \propto C_A C_B$ still proceeds efficiently due to high C_A.
- **Operating conditions:**
  - Maintain high T (within safety limits) to favor the desired path.
  - Large initial C_A, slow B feed to keep C_B small.
  - Stop the run as soon as A is mostly consumed to avoid further decomposition of B.

2. Plug Flow Reactor (PFR) with Distributed B Injection

- **Schematic:** Start the reactor with A only; inject small quantities of B at several points along the reactor.
- **Rationale:** Keeps C_B low at all points in the reactor, ensuring the desired reaction dominates.
- **Operating conditions:**
  - High, uniform temperature profile.
  - Split B into multiple side feeds; control feed spacing and rate to cap C_B at a low value.
  - Large excess of A at inlet.

General tips for both systems:

- Use dilution or solvent flow to further lower C_B.
- Minimize residence time to avoid excessive $B \to 2U$ conversion.
- Preheat B only immediately before mixing with A to reduce decomposition risk.