Regenerator of a Catalytic Cracking Unit

In the regenerator of a catalytic cracking unit the catalyst is regenerated by combustion of the coke deposited on the catalyst. The regenerator is a bubbling fluidized bed reactor. You are asked to design (size) a regenerator with the following characteristics:

1. The temperature inside the regenerator is spatially uniform at 900 K (you may use an isothermal model)
2. The operating pressure is 1 bar
3. Air is used for the combustion
4. The catalyst feed rate is 600 kg / s
5. The concentration coke on catalyst (Cc) of the inlet stream is 1 mol coke per kg catalyst (1 mol coke / $kg_{catalyst}$)

Your design has to meet the following demands:

1. The conversion of coke has to be in the range of 45% to 55%
2. The conversion of oxygen has a upper limit of 70%
3. The superficial gas velocity (u_0) has an upper limit of 1 m/s

You may use the following relations and assumptions:

- The reaction that is proceeds is:

  $2C + 1.5O_2 \rightarrow CO_2 + CO$

- The reaction rate is describe by:

$$-R_{O_2} = k \cdot \rho_{catalyst} \cdot Cc \cdot C_{O_2} \; [\frac{mol\ O_2}{m^3_{reactor} \cdot s}]$$

  With:

  Cc in mol C / $kg_{catalyst}$, C_{O2} in mol O_2 / m^3_{gas}, $\rho_{catalyst}$ in $kg_{catalyst}$ / $m^3_{reactor}$,

  k in m^3_{gas}/(mol C . s)

  $\rho_{catalyst}$ = 500 $kg_{catalyst}$ / $m^3_{reactor}$

- The rate constant k in the equation above is given by (T in K):

$$k = 10^9 e^{\frac{-18889}{T}}$$

- Oxygen transfer from the bubble to the dense phase can be described by a constant height of a transfer unit (H_T)

$$H_T = \frac{u_0}{K_m} = 1 * H^{0.5} * d_t^{0.42}(m)$$

In which K_m is in m^3/s gas transferred between bubble and dense phase per $m^3_{reactor}$, H is the height of the bed and d_t the diameter of the bed (both in m)

- For the hydrodynamics you may assume:
    a. Gas bubbles in plug flow
    b. Gas in the dense phase well mixed (CSTR)
    c. Solids well mixed (CSTR)

Furthermore, you may find inspiration in the lectures on the VanDeemter model.

Questions:

- How much air is required (in kg/s)? Take 50% conversion of coke and 50% conversion of oxygen
- Write a reactor model on basis of which the regenerator can be sized
- Present your design; give:
    a. The overall mass balance (input – output) over coke and oxygen
    b. The superficial velocity
    c. The concentration of coke on catalyst (mol C / $kg_{catalyst}$) in the reactor
    d. Axial profiles of oxygen in the bubble and dense phase
    e. The diameter en length of the reactor.