Hints to derive the gas flushing equation

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Here are some hints for deriving the gas flushing equation. We first define the fraction F:

$$F = \frac{\text{Volume of gas}}{\text{Volume of Jar}} = \frac{V_{gas}}{V_{jar}}$$

where the gas can be CO_2, Argon, etc. We can then write a small change in F as follows.

$$F + dF = \frac{1}{V_{jar}}\left[V_{gas} + dV_{flush} - FdV_{flush}\right] \tag{1}$$

where V_{gas} is the original amount of gas in the jar, and dV_{flush} is a small amount of gas pumped in to flush the jar. The third term on the right hand side, $-FdV_{flush}$ is motivated as follows. After dV_{flush} has instantaneously mixed with the whole volume of the mixture, a small amount of the mixture, dV_{mix} will escape.

$$dV_{mix} = dV_{flush},$$

and the amount of gas in the expelled dV_{mix} will be given by

$$(F + dF)dV_{mix} \approx FdV_{mix} = FdV_{flush}.$$

We can write the equation (1) as an ODE and solve it[1] to get the final equation,

$$F = 1 - e^{-\frac{V_{flush}}{V_{jar}}}.$$

Good luck!

[1] Show your work explicitly!