Problem 2.5 15 points:

Estimate the number of bubbles which can be simulated on the fastest supercomputer in the world (see https://www.top500.org/lists/top500/2022/11/).

Assume the following parameters:

1) Each computing core can process:

   (a) 2,048 **(b)** 4,096 and **(c)** 8,192 nodal points.

   (d) Assume that to compute every 1,000,000 nodal points, about 3.25 TFLOPS of "Rmax" power is required as listed in the Top500.org. Note that 1PFLOPS (peta-**fl**oating-point **o**perations **p**er **s**econd) = 1,000 TFLOPS (tera-) = 1,000,000 GFLOPS (giga-) = 10^{15} FLOPS.

2) Mesh resolution for each bubble is **(a)** 10 **(b)** 20 **(c)** 30 nodal points across the diameter.

3) The computational domain is a cube with uniform grid resolution in each direction: domain size is dictated by available computing power.

4) The bubble concentration is **(a)** 2% **(b)** 4% and **(c)** 8%.

5) Only: **(a)** 25% **(b)** 50% and **(c)** 75% **(d)** 100% of computing cores of the fastest machine are utilized for the computation.

(a) Provide the equations you used to make your estimates. Use the notation listed in the following table: (3 points)

n_{bub}	number of bubbles
N_c	total cores of a supercomputer
n_0	nodal points each computing core can process
n_d	nodal points across the diameter of each bubble
v_f	bubble concentration
a_v	availability of computing cores

(b) Results for all combinations of 1(a,b,c,d) – 2(a,b,c) – 4(a,b,c) – 5(a,b,c,d) must be determined. (6 points)

(c) Discuss the results and think of real multiphase flow systems (and their size) which can be simulated today using DNS approach. How is this affected by the choice of the parameters in 1)-5)? (6 points)

Extra credit (5 points): repeat the calculation for the fastest machine in top500 in June 2013 for case 1d – 2b – 4a – 5d and use it to estimate the computation power (Cores, Rmax, Number of nodal points in 1d, and the number of bubbles) in 2033 (assuming that the rate of growth in the next 10 years is the same as that in the last 10 years).

Solution:

(i) Provide the equations to estimate number of bubbles which can be simulated:

n_{bub}	number of bubbles
N_c	total cores of a supercomputer
n_0	nodal points each computing core can process
n_d	nodal points across the diameter of each bubble
v_f	bubble concentration
a_v	availability of computing cores

$$v_f = \frac{nodal\ points\ for\ all\ the\ bubbles}{nodal\ points\ in\ computational\ domain} = \frac{n_{bub}(\frac{4}{3}\pi(\frac{n_d}{2})^3)}{\mathrm{N_c.n_0 \cdot a_v}}$$

Hence, the number of bubbles which can be simulated:

$$n_{bub} = \frac{6v_f N_c n_0 a_v}{\pi \cdot (n_d)^3}$$

(b) The fastest supercomputer listed online for November 2022: OLCF Frontier.

Rank	System	Cores	Rmax (PFlop/s)	Rpeak (PFlop/s)	Power (kW)
1	**Frontier** - HPE Cray EX235a, AMD Optimized 3rd Generation EPYC 64C 2GHz, AMD Instinct MI250X, Slingshot-11, HPE DOE/SC/Oak Ridge National Laboratory United States	8,730,112	1,102.00	1,685.65	21,100

The total cores of this computer are $N_c = 8{,}730{,}112$; $R_{max} = 1{,}120\ PFLOPS$

With assumption 1(d), n_0 corresponding to Frontier:

$$n_0 = \frac{10^6 \times \frac{\mathrm{Rmax}}{3.25}}{N_c} = 38{,}839\ \mathrm{nodal\ points/core}$$

Evaluations for all 144 combinations, see the attached csv for the results.

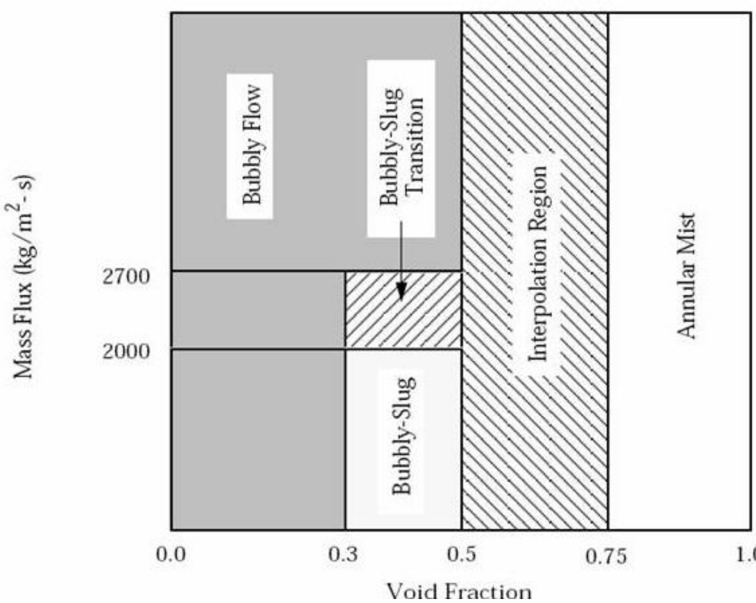
(c) Discuss the results:
Students could discuss the necessity of using supercomputer on doing DNS study based on the results in (i) and (ii).

Basic discussions:
the number of bubbles effected by parameters in 1)-5):

notation	Meaning	Effect on # (number of bubbles) which can be simulated
N_c	total cores of a supercomputer	proportional, linear
n_0	nodal points each computing core can process	proportional, linear
n_d	Mesh resolution for each bubble	inversely proportional, non-linear
v_f	bubble concentration	proportional, linear
a_v	availability of computing cores	proportional, linear

Deeper discussions:

1. In single bubble studies, the mesh resolution for bubble diameter ~2mm could be 30-50 elements, but this configuration is apparently not applicable for bubbly flow. In Combination 2, when we have 50 elements on bubble diameter, only 76 bubbles can be simulated.
2. Void fraction values in flow regime: as long as void fraction is below 30%, it is likely to be bubbly flow, which is the pre-assumption of this problem.



(The Basics of Two-Phase Flow, http://www.personal.psu.edu/jhm/470/lectures/3.html)

3. The availability of a supercomputer is very limited for each researcher (10% is already a very satisfying percentage).

Extra credit (5 points):
Fastest computer in Top 500 in June 2013

Rank	System	Cores	Rmax (TFlop/s)	Rpeak (TFlop/s)	Power (kW)
1	**Tianhe-2A** - TH-IVB-FEP Cluster, Intel Xeon E5-2692 12C 2.200GHz, TH Express-2, Intel Xeon Phi 31S1P, NUDT National Super Computer Center in Guangzhou China	3,120,000	33,862.70	54,902.40	17,808

1(d): the number of nodal points that each core can process is:

$$\frac{1000000 \times \frac{\text{Rmax}}{3.25}}{\text{Nc}} = \frac{1000000 \times \frac{33862.7}{3.25}}{3120000} = 3338$$

Combination: 1(d) – 2(b) – 4(a)– 5(d):

Use the expression in (a), the number of bubbles is 49,740.

For 2033:

$$N_{c,2033} \approx N_{c,2023} \frac{N_{c,2023}}{N_{c,2013}} = 24{,}427{,}838$$

Similarly,

$$R_{max,2033} = R_{max,2023} \frac{R_{max,2023}}{R_{max,2013}} = 35863\ PFLOPS$$

Hence, for 2033:

$$n_0 = \frac{10^6 R_{max,2033}}{3.25 N_{c,2033}} = 451{,}733$$

Based on the result of (a) and 1(d) – 2(b) – 4(a)– 5(d):

$$n_{bub} = 52{,}687{,}578$$

which is a significant increase compared with it in 2013.