Appendices

A C++ code

```
#include <imgui-SFML.h>
#include <SFML/Window/Mouse.hpp>
#include <imgui.h>
#include <SFML/System/Vector2.hpp>
#include <SFML/Graphics.hpp>
#include<iostream>
#include <algorithm>
#include<vector>
#include<cmath>
#include <omp.h>

using namespace std;

static int particle_num = 1600;
static float particle_mass = 30.f;
const int particle_radius = 5;
const float collision_damping = 0.8f;
const float pi = 3.141f;
static float target_density = 100.f;
static float pressure_multiplier = 75.f;
static float smoothing_radius = 70.f;
const float dt = 1.f/60.f;
static float gravity = 0.f;
static int framerate = 60;
static int viscosity_strength = 10.f;
static bool interactive = false;

struct particle{
    sf::CircleShape droplet{particle_radius};
    sf::Vector2f position{0.f, 0.f};
    sf::Vector2f velocity{0.f, 0.f};
    float local_density = 1.f;
    float local_pressure = 1.f;
    sf::Vector2f predicted_position{0.f, 0.f};
};

vector<particle> particles(particle_num);


void placeParticles(){
    int particlesPerRow = sqrt(particle_num);
    int particlesPerColumn = (particle_num - 1)/particlesPerRow + 1;
    int spacing = 2.5*particle_radius;
    for (int i = 0; i < particle_num; i++){
        particles[i].position.x = (i % particlesPerRow + particlesPerRow / 2.5f
            +0.5f) * spacing;
        particles[i].position.y = (i / particlesPerRow + particlesPerColumn /
            2.5f +0.5f) * spacing;
    }
}

void resolveGravity(int i){
    particles[i].velocity.y += gravity * dt;
}

void predictPositions(int i){
    particles[i].predicted_position.x = particles[i].position.x +
        particles[i].velocity.x * dt;
    particles[i].predicted_position.y = particles[i].position.y +
        particles[i].velocity.y * dt;
}

float smoothingKernel(double dst){
    float volume = pi * (float)(pow(smoothing_radius, 4.0)/2);
    if (dst >=smoothing_radius){
        return 0.f;
    }
    float value = (float)pow(smoothing_radius - dst, 3);
    return value/volume;
}
float smoothingKernelDerivative(double dst){
    if (dst >= smoothing_radius) return 0.0;
    float value = -6.f * (smoothing_radius - dst) * (smoothing_radius - dst) /
        (pi * pow(smoothing_radius, 4));
    return value;
}
float calculateDensity(int i){
    float density = 0.f;
    for (int j =0; j < particle_num; j++){
        float dst = sqrt((particles[j].predicted_position.x -
            particles[i].predicted_position.x) *
            (particles[j].predicted_position.x -
            particles[i].predicted_position.x) +
            (particles[j].predicted_position.y -
            particles[i].predicted_position.y) *
            (particles[j].predicted_position.y -
            particles[i].predicted_position.y));
        float influence = smoothingKernel(dst);

        density += particle_mass * influence;
    }
    return density;
```

```
}

float densityToPressure(int j){
    float density_error = particles[j].local_density - target_density;
    float local_pressure = density_error * pressure_multiplier;
    return local_pressure;
}

float sharedPressure(int i, int j){
    float pressurei = densityToPressure(particles[i].local_density);
    float pressurej = densityToPressure(particles[j].local_density);
    return (-(pressurei + pressurej) / 2.f);
}

sf::Vector2f calculatePressureForce(int i){
    sf::Vector2f pressure_force;
    sf::Vector2f viscosity_force;
    for (int j = 0; j<particle_num; j++){
        if (i == j) continue;
        float x_offset;
        float y_offset;
        if (particles[i].predicted_position == particles[j].predicted_position){
            x_offset = (float)1+ (rand() % 20);
            y_offset = (float)1+ (rand() % 20);
        }
        else{
            x_offset = particles[j].predicted_position.x -
                particles[i].predicted_position.x;
            y_offset = particles[j].predicted_position.y -
                particles[i].predicted_position.y;
        }
        double dst = sqrt(abs(x_offset * x_offset + y_offset * y_offset));
        float gradient = smoothingKernelDerivative(dst);
        float x_dir = x_offset/dst;
        float y_dir = y_offset/dst;
        // Newton's 3rd law implementation below
        float shared_pressure = sharedPressure(i, j);
        pressure_force.x += shared_pressure * gradient *
            particle_mass/particles[j].local_density * x_dir;
        pressure_force.y += shared_pressure * gradient *
            particle_mass/particles[j].local_density * y_dir;
    }
    return pressure_force;
}

sf::Vector2f calculateViscosityAcceleration(int i){
    sf::Vector2f viscosity_acceleration;
    float dst;
    for (int j; j<particle_num; j++){
        if (i==j) continue;
        dst = sqrt((particles[i].predicted_position.x -
            particles[j].predicted_position.x) *
            (particles[i].predicted_position.x -
            particles[j].predicted_position.x) +
            (particles[i].predicted_position.y -
            particles[j].predicted_position.y) *
            (particles[i].predicted_position.y -
            particles[j].predicted_position.y));
        viscosity_acceleration.x -= (particles[i].velocity.x -
            particles[j].velocity.x) * (smoothingKernel(dst)) *
            viscosity_strength;
        viscosity_acceleration.y -= (particles[i].velocity.y -
            particles[j].velocity.y) * (smoothingKernel(dst)) *
            viscosity_strength;
        if (viscosity_acceleration.x > 0 || viscosity_acceleration.y > 0){
            viscosity_acceleration.x = 0;
            viscosity_acceleration.y = 0;
        }
    }
    return viscosity_acceleration;
}

void resolveCollisions(int i, sf::Vector2u window_size){
    if (particles[i].position.x > window_size.x || particles[i].position.x < 0){
        particles[i].position.x = clamp((int)particles[i].position.x, 0,
            (int)window_size.x);
        particles[i].velocity.x *= -1;
    }
    if (particles[i].position.y >= window_size.y || particles[i].position.y <=
        0){
        particles[i].position.y = clamp((int)particles[i].position.y, 0,
            (int)window_size.y);
        particles[i].velocity.y *= -1;
    }
}

void resolveColour(int i, float vel){
    int b = clamp((int)(-255/50 * vel + 255), 0, 255);
    int r = clamp((int)(255/50 * vel -255), 0, 255);
    int g = clamp((int)(-abs(255/50 * (vel-50))+255), 0, 255);
    particles[i].droplet.setFillColor(sf::Color(r, g, b));
}

sf::Vector2f interactiveForce(sf::Vector2i position, int i, float repulsive){
    sf::Vector2f force;
    float dst = (particles[i].position.x - position.x) *
        (particles[i].position.x - position.x) + (particles[i].position.y -
        position.y) * (particles[i].position.y - position.y);
    if (dst<=10000){
        force += (((sf::Vector2f)position) - particles[i].predicted_position) *
            (100-sqrt(dst))/4.f * repulsive;
    }
    return force;
}

int main()
{
    //Initialize SFML
    sf::RenderWindow window(sf::VideoMode(900, 900), "Smoothed Particle
        Hydrodynamics Simulation");
    window.setFramerateLimit(framerate);
    sf::View view = window.getDefaultView();
    sf::Vector2u window_size = window.getSize();
    placeParticles();
    ImGui::SFML::Init(window);
    sf::Vector2i position;
    float repulsive = 1;
    sf::Clock deltaClock;
    while (window.isOpen())
    {
        sf::Event event;
        while (window.pollEvent(event))
        {
            ImGui::SFML::ProcessEvent(event);
            if (event.type == sf::Event::Closed)
                window.close();
            if (event.type == sf::Event::Resized){
                sf::FloatRect visibleArea(0.f, 0.f, event.size.width,
                    event.size.height);
                window.setView(sf::View(visibleArea));
            }
            if (event.type == sf::Event::MouseButtonPressed){
                interactive = true;
                if (event.mouseButton.button == sf::Mouse::Left){
                    repulsive = 1.f;
                }
                else{
                    repulsive = -1.f;
                }

            }
            if (event.type == sf::Event::MouseButtonReleased){
                interactive = false;
            }
        }
        sf::Vector2u window_size = window.getSize();
        ImGui::SFML::Update(window, deltaClock.restart());
```

```
window.clear();

//ImGui Menu
ImGui::Begin("Menu");
ImGui::SliderInt("Particle Num", &particle_num, 1, 1600);
ImGui::SliderFloat("Particle Mass", &particle_mass, 10.f, 100.f);
ImGui::SliderFloat("Target Density", &target_density, 0.f, 500.f);
ImGui::SliderFloat("Pressure Multiplier", &pressure_multiplier, 0.f,
    1000.f);
ImGui::SliderFloat("Smoothing Radius", &smoothing_radius, 10, 200);
ImGui::SliderFloat("Gravity", &gravity, 0.f, 100.f);
ImGui::End();
sf::CircleShape circle;
position = sf::Mouse::getPosition(window);
for (int i = 0; i < particle_num; i++){
    resolveCollisions(i, window_size);
    //gravity step
    resolveGravity(i);
    //Predict next positions
    predictPositions(i);
    // window bounding box
    //calculate densities
    particles[i].local_density = calculateDensity(i);
    //convert density to pressure
    particles[i].local_pressure = densityToPressure(i);
    //Calculate pressure forces and acceleration
    sf::Vector2f pressure_force = calculatePressureForce(i);
    if (interactive){
        pressure_force += interactiveForce(position, i, repulsive);
    }
    sf::Vector2f pressure_acceleration;
    pressure_acceleration.x =
        pressure_force.x/particles[i].local_density;
    pressure_acceleration.y =
        pressure_force.y/particles[i].local_density;
    //Calculate acceleration due to viscosity
    pressure_acceleration += calculateViscosityAcceleration(i);
    particles[i].velocity.x += pressure_acceleration.x * dt;
    particles[i].velocity.y += pressure_acceleration.y * dt;
    //resolve colour
    float vel = sqrt(particles[i].velocity.x * particles[i].velocity.x
        + particles[i].velocity.y * particles[i].velocity.y);
    resolveColour(i, vel);// add at the end
    //calculate particle positions with radius offset
    particles[i].position.x += particles[i].velocity.x * dt;
    particles[i].position.y += particles[i].velocity.y * dt;
    //set particle position on screen
    particles[i].droplet.setPosition(particles[i].position.x+particle_radius,
        particles[i].position.y+particle_radius);
```

```
         //render particle
         window.draw(particles[i].droplet);
      }
      ImGui::SFML::Render(window);
      window.display();

   }
    ImGui::SFML::Shutdown();

   return 0;
}
```

B Media

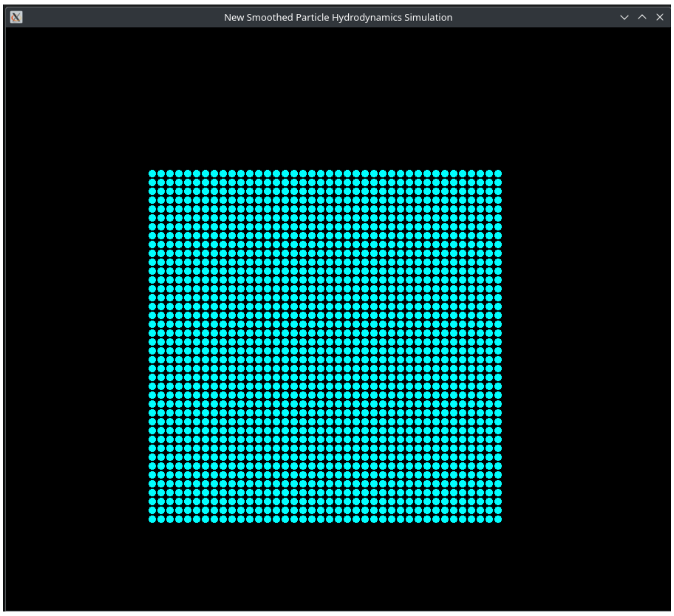


Figure 1: Cyan particles rendered on screen.

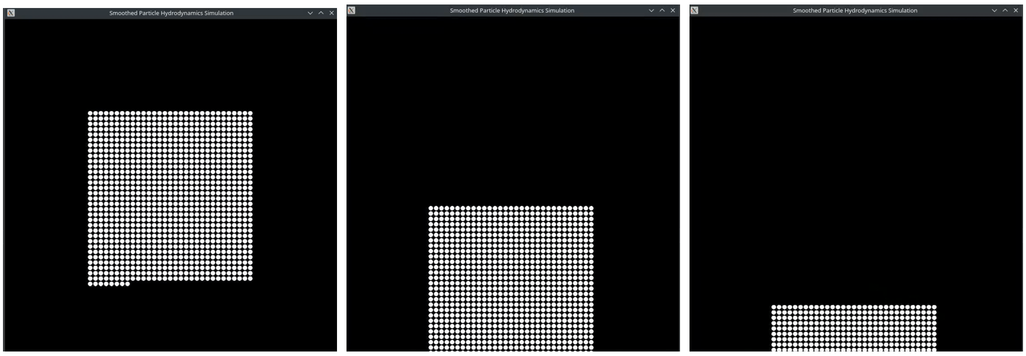

Smoothed Particle Hydrodynamics Simulation
Smoothed Particle Hydrodynamics Simulation
Smoothed Particle Hydrodynamics Simulation

Figure 2: Gravity with no collision with screen border.

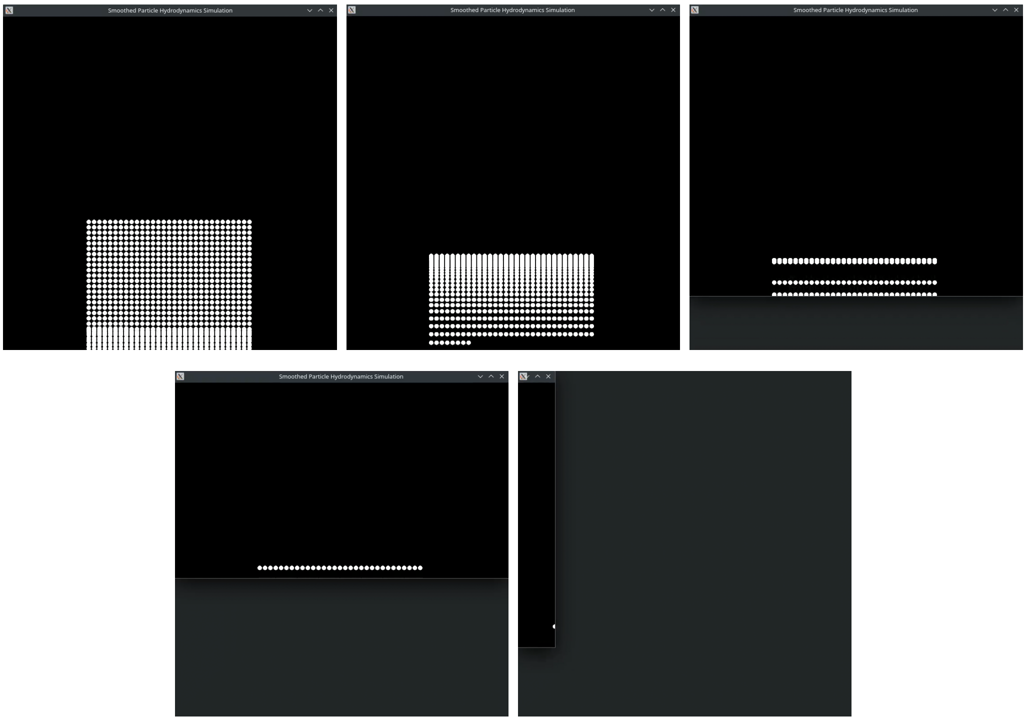
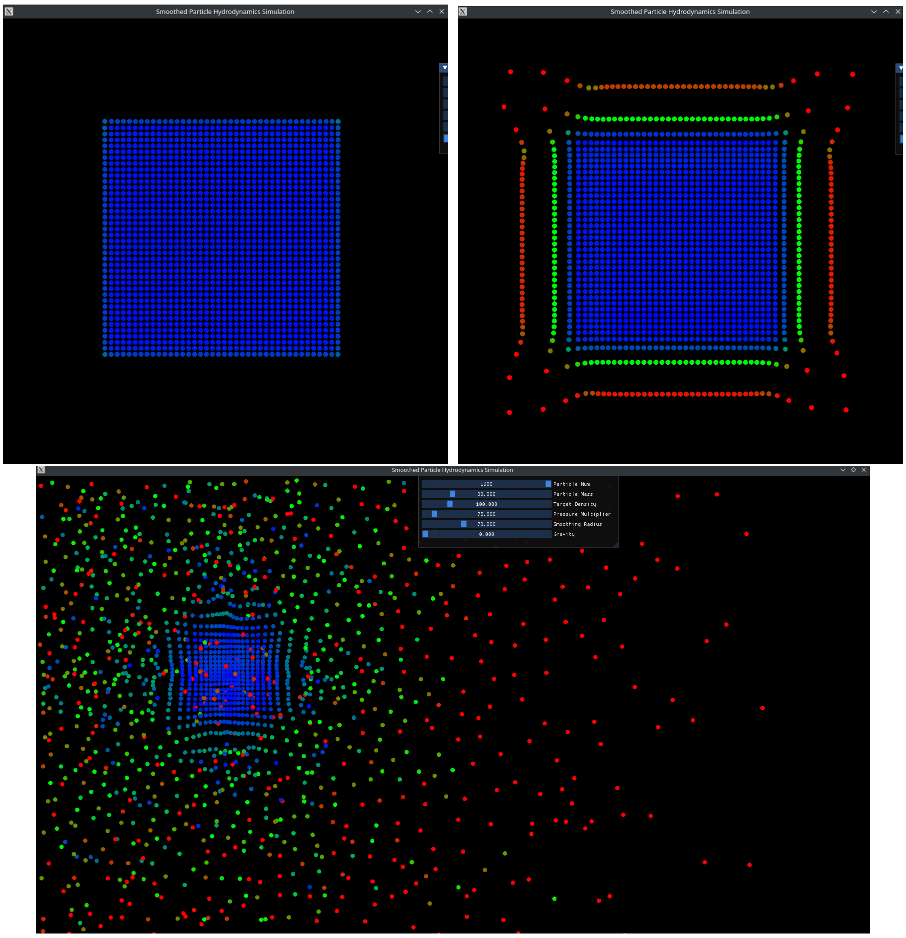
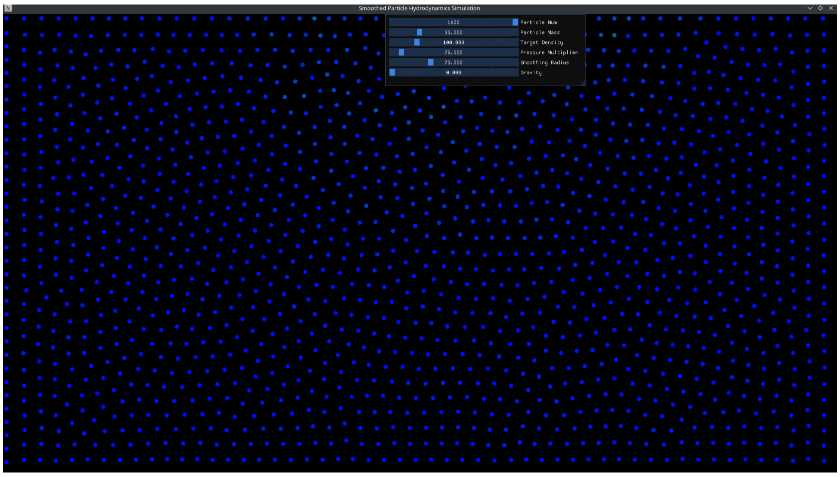


Figure 3: Gravity with collision and window resizing.


Smoothed Particle Hydrodynamics Simulation
Smoothed Particle Hydrodynamics Simulation
Smoothed Particle Hydrodynamics Simulation

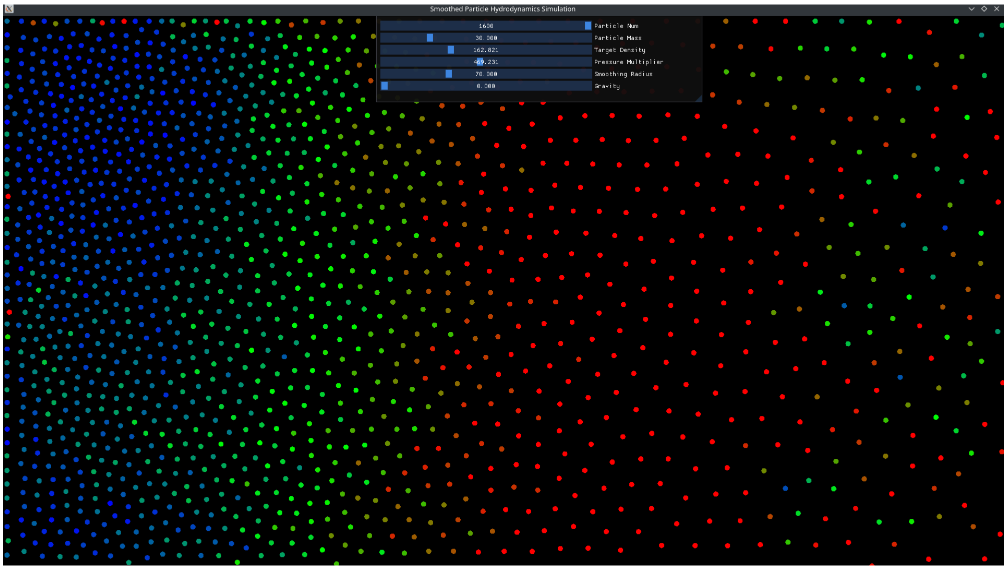
```
1600      Particle Num
30.000    Particle Mass
100.000   Target Density
75.000    Pressure Multiplier
70.000    Smoothing Radius
0.000     Gravity
```

Figure 4: Fluid particles moving down the pressure gradient.



```
1600      Particle Num
30.000    Particle Mass
100.000   Target Density
75.000    Pressure Multiplier
70.000    Smoothing Radius
0.000     Gravity
```

Figure 5: Fluid particles reaching a constant density in a stable state.



1600 Particle Num

30.000 Particle Mass

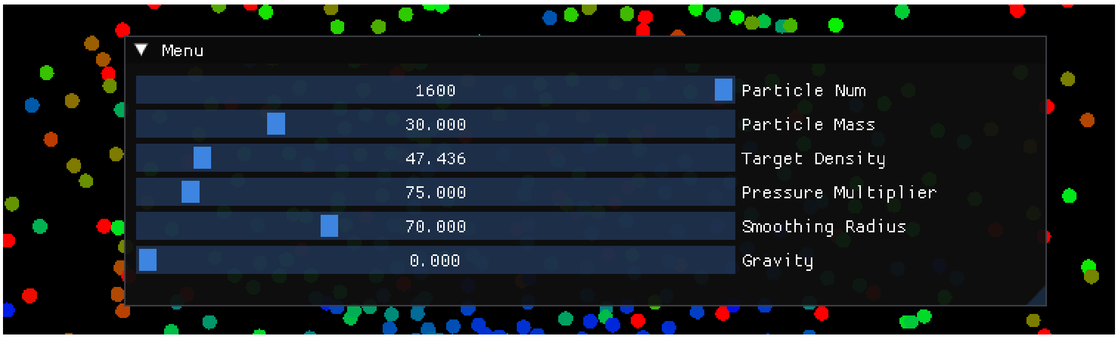
162.821 Target Density

469.231 Pressure Multiplier

70.000 Smoothing Radius

0.000 Gravity

Figure 6: Red particles with high velocities becoming green at the edge, displaying viscosity



1600 Particle Num

30.000 Particle Mass

47.436 Target Density

75.000 Pressure Multiplier

70.000 Smoothing Radius

0.000 Gravity

Figure 7: ImGui sliders on screen.

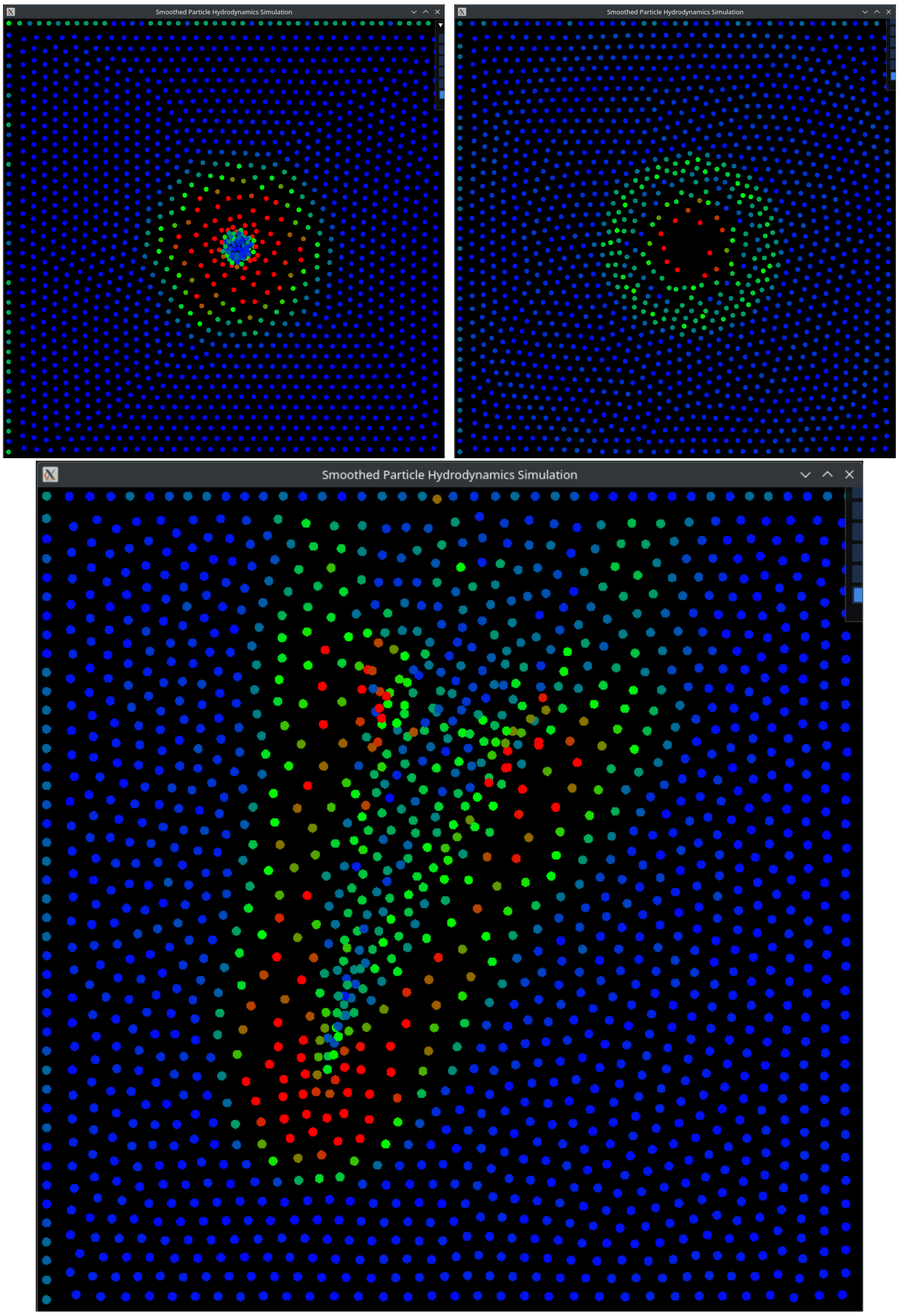

Smoothed Particle Hydrodynamics Simulation
Smoothed Particle Hydrodynamics Simulation
Smoothed Particle Hydrodynamics Simulation

Figure 8: Attractive and repulsive mouse forces with mouse drag effect.

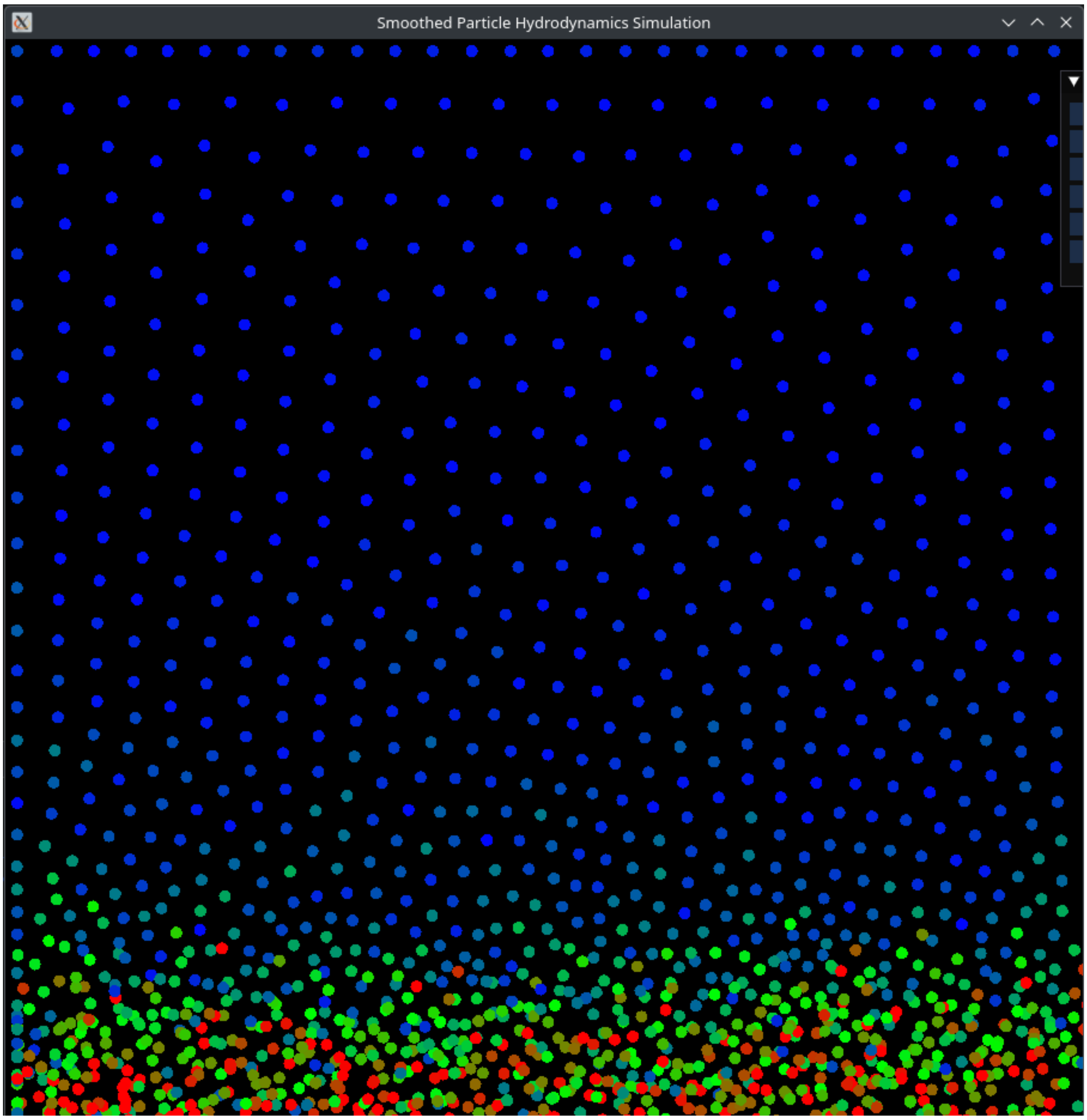
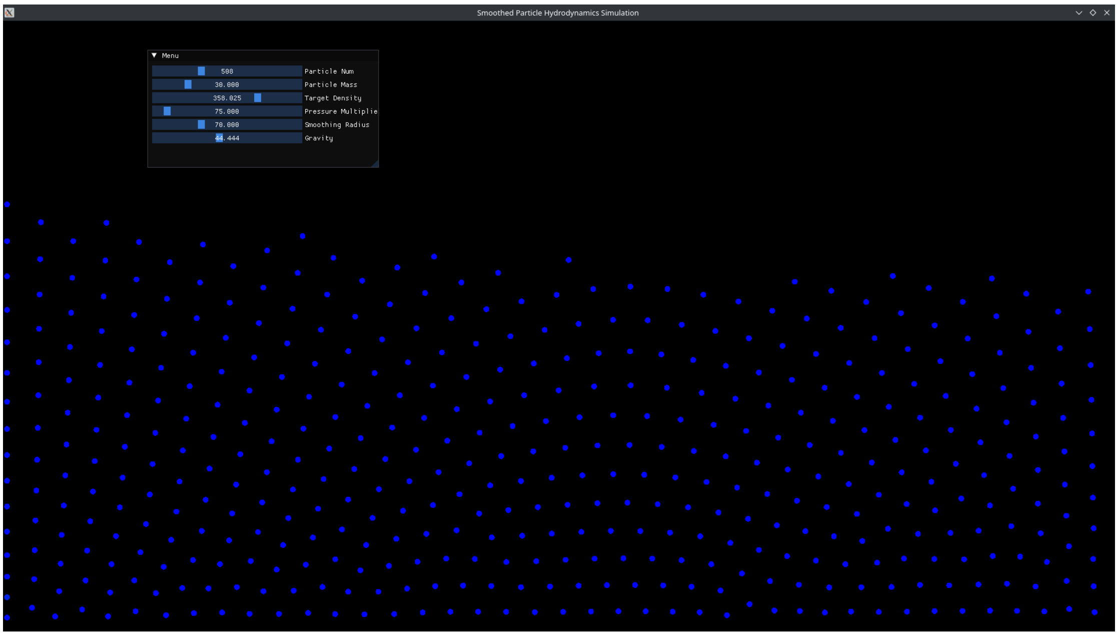


Figure 9: Fluid with gravity behaving like a boiling liquid or heavy gas.



508 Particle Num
30.000 Particle Mass
358.025 Target Density
75.000 Pressure Multiplie
70.000 Smoothing Radius
44.444 Gravity

Figure 10: Fluid with gravity giving an unsmooth surface.