# Computational Fluid Dynamics Analysis of Sparger Systems in Electroless Nickel Plating Processing Tank

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**Abstract**

Research on Electroless Nickel Plating (ENP) process has been quite intensive in the past decade. Whilst there have been many studies analyzing the quality of the electroless nickel deposits on the substrate of interest, the flow dynamics in the process tank, especially those using computational simulation are scarce. In this study, the flow dynamics from two types of sparger systems namely Piping-Sparger (PS) and Perforated-Plate-Sparger (PPS) were simulated using FLUENT software. Multiphase computational fluid dynamics (CFD) method of volume of fluid (VOF) was used to analyze fluid flow in the ENP processing tank. A constant mass flow rate was used for both sparger systems in order to determine the velocity profiles and the flow field across the processing tank. The results showed improvements in terms of velocity distribution by PPS. It is expected that the optimized flow dynamics by the PPS system is beneficial in promoting homogenous chemical composition in the ENP processing tank, providing consistent and uniform coverage of chemical, removing hydrogen bubbles from the surface to be plated effectively and encouraging by-product or other suspended contaminant moves away from processing tank and into the filtration system.

**Keywords:** Electroless nickel plating, FLUENT VOF, Sparger system, Piping Sparger, Perforated Plate Sparger, Electroless nickel plating processing tank.

## 1. Introduction

The electroless nickel plating process (ENP) is widely used to deposit nickel on substrate (with specific dimensions) surface [1], [2] without the external source of energy in order to initiate the reaction and normally known as “electro-less”. The ENP is being applied in various industry such as electronic applications [3], chemical, aerospace, automobile, textile and biomedical devices industry [4], [5]. The advantage of ENP process are uniform deposits thickness regardless of substrate geometry, smooth thickness with relatively defect-free coverage, sustain amorphous micro-structure at elevated temperature and better corrosion resistance [5]–[8]. Normally two basic components of the ENP solution are a source of nickel, commonly nickel sulfate salt and a reducing agent, typically sodium hypophosphite [9], [10]. Besides that, the ENP solution also contains other miscellaneous ingredients such as complexants, accelerators, stabilisers, buffers, pH regulators and wetting agents [11]–[14]. During the plating process, hypophosphite is also reduced to phosphorus and co-deposited onto the catalytic surface together with nickel. Therefore, the metal deposited is considered as an alloy of nickel and phosphorus (NiP) at predetermined ratio [15], [16].

ENP process tank can be divided into two segments namely main tank and two sets of small tanks or known as weir at each side. The ENP chemical solution will overflow to the weir and later to the filtration system and return to the main processing tank through sparger (Typical sparger is made of 2” hollow SS316 pipe with definite orifice size, number and configuration). The ideal fluid dynamic in the ENP processing tank is very important:-

1. To ensure homogenous chemical composition in the processing tank.
2. To promote consistent/uniform coverage of chemicals to the substrate to be plated.
3. To remove hydrogen bubbles from the substrate surface effectively.
4. To induce by-product and other suspended contaminant away from the processing tank into the filtration system.

Since the chemical ions (For example $Nickel^{2+}$) do not have any preference to go to the specific area on the substrate surface to be plated, hence the flow dynamics in the ENP processing tank is the only driving force available to do so.

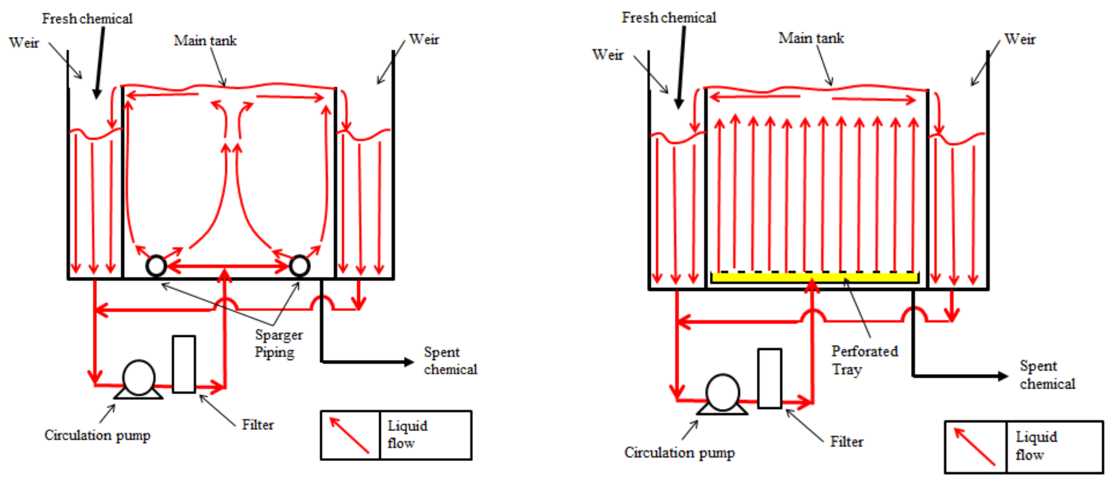
Process Control parameters such as temperature, pH, bath compositions, bath loading and bath age are very important for ENP process performances as they will determine the characteristic of NiP deposited such as surface morphology and corrosion resistance. However, the effect of flow dynamics is far from being fully understood. Most of the available material such as technical paper and articles are discussing about agitation effects to describe the fluid behavior in the ENP process for various applications. Riedel suggests that the agitation or work movement is advisable for ENP process as it will help to transport the reactant and remove the spent reaction products from the surface to be plated effectively [11]. In addition, agitation need to be controlled as it will affect nickel coating properties [17].

Better agitation will lead particles to the pump intake accordingly and minimize hydrogen bubble retention on the substrate surface, especially for bottom and side types of sparger system [18]. Notwithstanding conventional experiment method, computational fluid dynamic (CFD) technique has been applied to analyse the flow characteristics in ENP processing tank [19], [20]. As a conclusion, agitation plays a vital role in ENP processing tank as it will determine the properties of the NiP deposited onto article to be plated and CFD method is practicable to study its flow dynamic in details. In addition CFD has been universally recognized as an essential tool for engineering analyses associated with transport phenomena in various applications.

In this paper, we demonstrate the use of CFD method to study the flow dynamics in the ENP processing tank. The main objective is to analyse the flow fields in the main processing tank for two different sparger systems; the Piping-Sparger (PS) and the Perforated-Plate-Sparger (PPS).

## 2. Methodology

The electroless plating processing tank is shown in Fig. 1. The tank can be divided into two segments namely main processing tank and two sets of small tanks or weir at each side. The chemical solution will overflow to the small tank and later to the filtration system and return to the main processing tank via sparger. In the PS system (Fig. 1a) there are two small pipes connected to a main inlet piping. The small pipes have a number of orifices located at predetermined degrees from each other and spread along the sides of the pipe. While for the PPS system (Fig. 1b), a perforated tray is installed on top of the rearranged small pipe configuration so that the solution can be diffused uniformly into the ENP processing tank.



(a) (b)

Figure 1: Schematic diagram of Sparger system (a) PS, and (b) PPS.

The fluid in the main processing tank is considered immiscible, incompressible and Newtonian fluid. The governing equations for the flow are the continuity and the momentum equations expressed as

$$\nabla \cdot \mathbf{u} = 0 \tag{1}$$

and

$$\frac{\partial(\rho \mathbf{u})}{\partial t} + \nabla \cdot (\rho \mathbf{u}\mathbf{u}) = -\nabla p + \nabla \cdot \tau + \mathbf{F}_B + \mathbf{F}_{ST} \tag{2}$$

where p denotes pressure, $\mathbf{F}_B$ represents body forces, $\mathbf{F}_{ST}$ is the surface tension force and $\tau$ is the shear stress force. The fluid properties at any point are calculated as follow

$$\rho(f) = f\rho_1 + (1-f)\rho_2 \tag{3}$$

and

$$\mu(f) = f\mu_1 + (1-f)\mu_2 \tag{4}$$

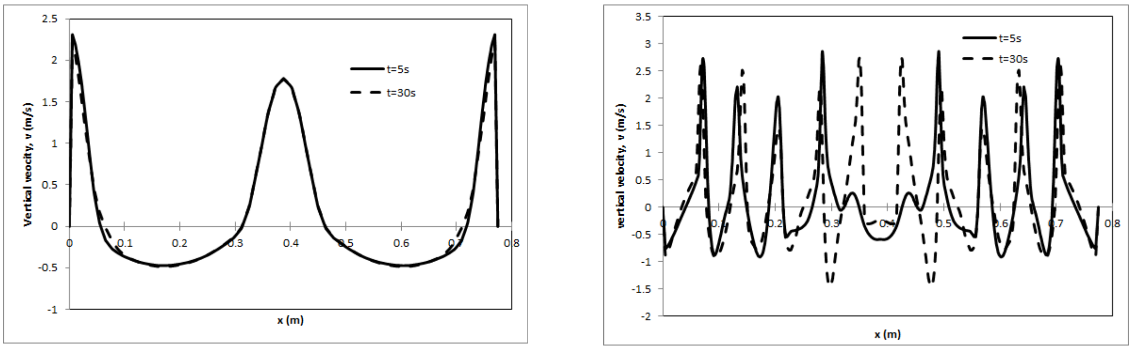
where subscript 1 and 2 refers to fluids 1 and 2 respectively. Here f is the volume fraction of each numerical cell occupied by fluid 1 or 2. The advection equation for f is also solved as

$$\frac{\partial f}{\partial t} + \mathbf{u} \cdot \nabla f = 0 \tag{5}$$

The inlet velocity is set at 6 m/s at the orifices of small pipes for both sparger systems. A mesh size of 16454 was found to be suitable for the current investigation.

## 3 Result and Discussion

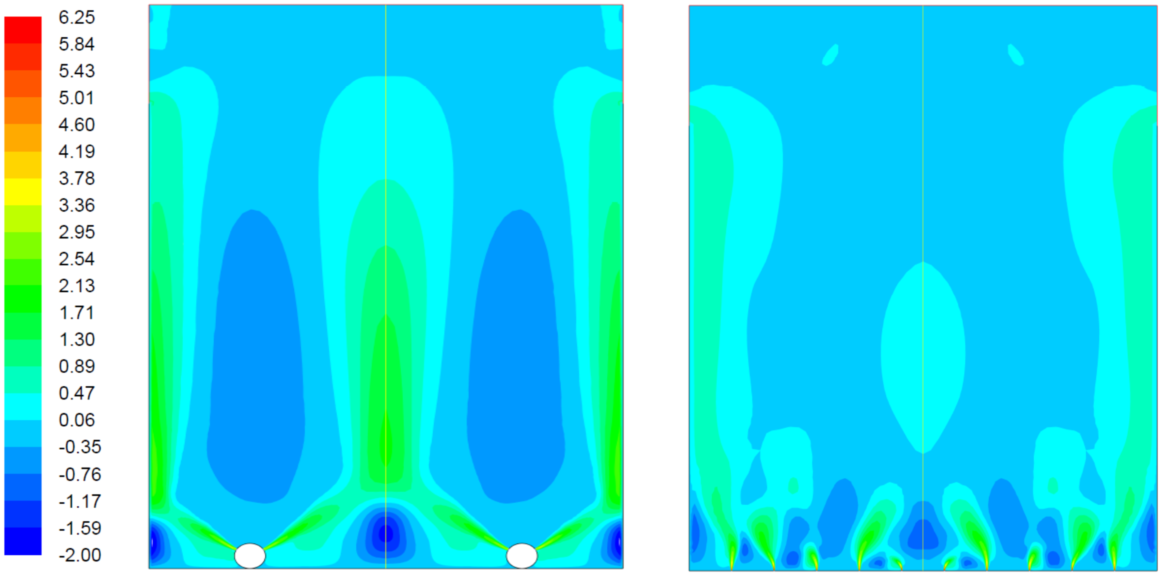
The current paper investigates the flow dynamics in ENP processing tank using two types of sparger system. The FLUENT software with volume of fluid CFD tool was used to solve the governing equation of multiphase fluid flow. Figure 2 shows the vertical velocity profiles at the slightly above both sparger system. As can be seen from the figures, the PPS system gives uniform vertical flow that lead to better agitation across the ENP processing tank. Better agitation of the chemical will improve the NiP deposited uniformity due to mass transfer enhancement [21], [22]. On the other hand, the vertical flow for PS system is ununiformed and only concentrated at the edge and the middle of the processing tank.




(a) (b)

Figure 2: Vertical velocity profile (a) PS, and (b) PPS.

The obtained vertical velocity contours from both sparger systems are shown in Fig. 3. All of the results are in line with the expected results where the flow field is more uniform by the PPS. This characteristic is significant to ensure that the solution is uniformly distributed across the tank which in turn provides good coverage of the chemical towards article to be plated in the ENP processing tank. This will lead to better and consistent NiP coating quality.




(a) (b)

Figure 3: Vertical velocity contour (a) PS, and (b) PPS.

## 4 Conclusion

Numerical computations of flow dynamics in ENP processing tank were performed using FLUENT. A computational fluid dynamics tool of volume of fluid technique was applied to solve multiphase fluid flow in the tank. Results of the present computations show the flow fields in the ENP processing tank produced by two types of sparger system specifically PS and PPS. Unsurprisingly, the flow field distributed more uniformly for the PPS system compared to the PS system. The flow was injected uniformly upward from perforated tray to ensure consistent coverage of chemical solution towards the surface of the substrate to be plated which lead better NiP deposited uniformity.

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