Presented in the ECWC 10 Conference at IPC Printed
Circuits Expo®, SMEMA Council APEX® and
Designers Summit 05

Improving Printed Circuit Board Plating with Eductor Agitation

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Abstract
This paper will review eductor agitation systems at PWB installations to improve the electroplating of printed circuit boards. Significant environmental and productivity improvements have been realized through the use of carefully engineered clusters of eductor nozzles. Design parameters, materials of construction, turnover rates and pump selection will be discussed. Reported benefits such as reduced airborne emissions, faster and more uniform plating rates and prevention of solution stratification to improve filtration will be reviewed.

Introduction
Solution agitation has been an ever-present requirement for printed circuit board manufacturers for several decades. As electrolytes developed, the need for agitation and good filtration for that matter also became increasingly important to maximize the efficiency and performance of new chemical processes.

The introduction of better, more effective filtration systems really paved the way for solution movement to be considered as a practical way of improving the performance of processes driven by an ever increasing cost conscious production environment.

The rate of acid copper plating on printed wiring boards for many years has been limited by the current density to which we could subject the boards. No one could "safely" run above 25 ASF, because of burning in the high current density areas. The breakthrough to higher productivity has occurred with the introduction of pump powered eductor agitation systems. Carefully engineered clusters of eductor nozzles sweep away cathode films swiftly, allowing faster plating rates at lower voltages with much higher current densities.

Reasons for Agitating Solutions
1. To provide a mass movement of solution around the tank to generate a completely homogenous solution. Homogenous solutions can lead to surface quality enhancement.
2. To provide a constant supply of plating ions (Figure 1) along with other brighteners and wetting agents to the substrate. Burning occurs when the solution immediately surrounding work, often called the diffusion layer, becomes depleted of ions.
1. The avoidance of burning in high current density areas usually limits the current at which successful electrolysis can take place. Therefore, constant replenishment of fresh solution around the substrate often facilitates plating at higher current.
2. To prevent settlement of particulate, thus aiding filtration. To maintain a crystal clear solution requires good agitation and a filter
3. System with an appropriate flow rate, dirt holding capacity and media selection.
4. To disperse hydrogen away from work interface thus preventing gas pitting.
5. To eliminate temperature stratification – processes will perform at their peak if temperature is constant throughout the process tank.
6. To encourage dissolution of anode materials.

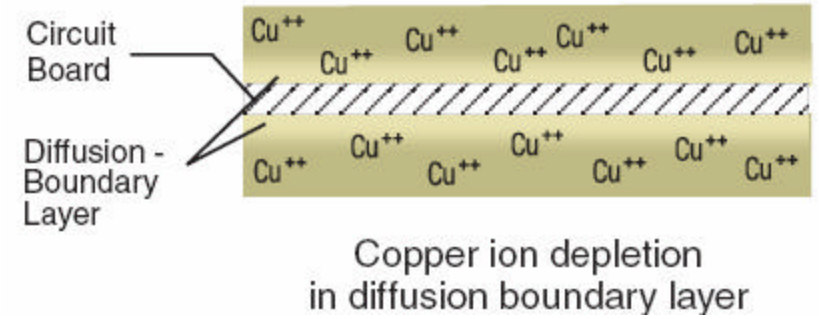

Figure 1 – Plating Ions at the Substrate Surface

Common Methods of Solution Agitation

Air Agitation

Regenerative (oil-less) air systems consist of a blower to provide air at constant pressure and distribution piping with perforations to bubble air through the solution (Figure 2).

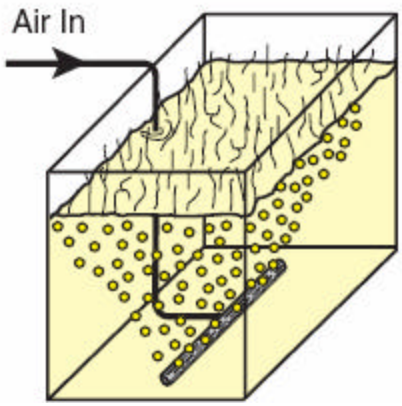

Figure 2 – Air Agitation

Cathode Rod Agitation

Side to side movement of cathode bars attached to rollers on the tank flange. Cathode rod agitators (Figure 3) move slowly, providing horizontal oscillation at one or two inches per second with linear travel of two to four inches.

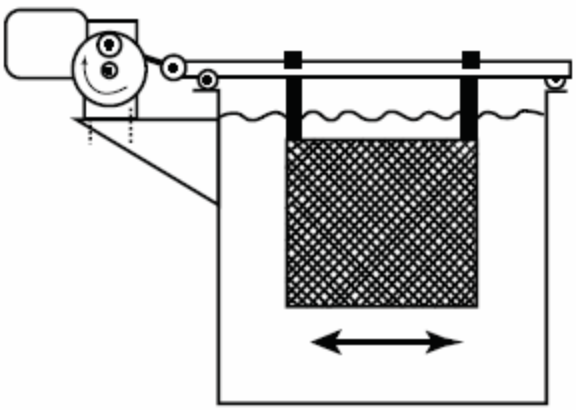

Figure 3 – Cathode Rod Agitation

Pumped Flow Eductor Agitation

Figure 4 illustrates the principle focus of this paper…eductor agitation. The eductors are ganged on a pipe manifold to provide even distribution of flow and are driven by a pump of sufficient power to achieve the desired level of agitation

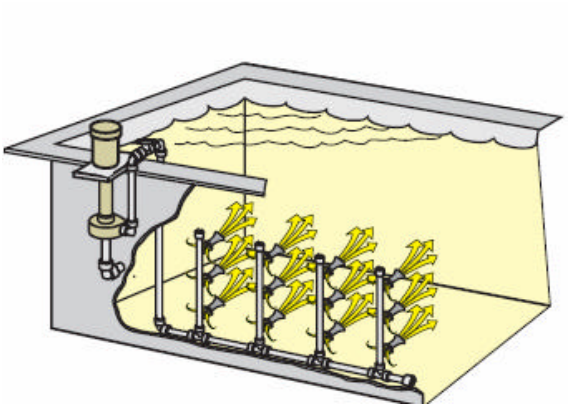

Figure 4 – Pumped Flow Eductor Agitation

Problems with Air Agitation
Air agitation is often very uneven as sparger pipes block. It is very common to see plating tanks that are highly turbulent in one corner yet static in other areas. Accelerating heat and chemical losses to the air. As the air bubbles explode latent heat leaves the tank thereby increasing the energy requirements to maintain operating temperature. This has a huge impact on the cost of operating a plant and is particularly relevant when considering the climate change levy.

Due to the explosion of air bubbles on the surface of the solution, foam and noxious chemical fumes are produced which create an unpleasant and potentially dangerous working environment as well as increasing the need for extraction. This also impacts greatly on the fabric of buildings and on the health and safety of tank side personnel. Air is inherently non-conductive thereby reducing the efficiency of the electrolyte. Brightener usage is increased through oxidation.

Limitations of Cathode Rod Agitation
This type of agitation has several limitations; the speed at which the work can move is slow and the distance the cathode moves requires extra length, which then results in lost cathode space.

The work is only moving within the envelope of solution surrounding it, so very little mixing occurs and therefore temperature stratification can result and the overall performance of the process diminishes.

Principal of Eductor Nozzle Operation
Eductor nozzles use the venturi principle to amplify and direct solution flow from the pump to the required area of the tank (Figure 5).

For one gallon of solution pumped through the eductor at the required pressure, the discharge flow from the nozzle will be five gallons.

In simple terms a very high tank turnover rate of solution can be achieved from a relatively small pump. Solution can be directed easily within the tank with strategic positioning of the nozzles.

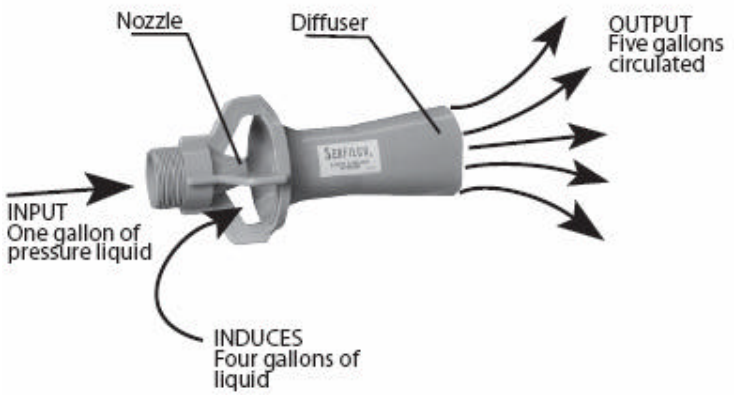

Figure 5 – Venturi Effect in Eductor Nozzles

Case Study: United Electronics
United Electronics Corp. of Rosemont, Illinois manufactures high volume double-sided and specialty multi-layer circuit boards. Their new manufacturing facility boasts state-of-the-art equipment which was specified to maximize production rates while lowering reject rates. Key to this goal was the design and installation of eductor agitation systems.

The eductor systems were installed on two 2,000 gallon acid copper plating tanks. Each system was composed of 1-15 HP pump, 60 - ¾" eductor nozzles and related piping.

In two years since the eductor system was operational, United Electronics not only cut plating time in half, they improved the quality of the plating as well. What was a 24 hour work load before pump powered eductors were installed, now takes only 10 hours to complete. One of the biggest problems in the printed circuit industry until now was uneven electrolytic copper plating ("dog-boning"). Using eductors, United Electronics is now able to plate much more uniformly at 30-50 amps per square foot. Plating 2 mil lines, 2 mil spaces and .002 blind vias is now easier and faster, due to the high volume solution turnover of 2,000 gallons per minute.

Of further (and perhaps greatest) significance, is the savings in copper anode usage attributed to reducing the variation in plate thickness. The new line was projected to use 30,000 pounds of copper anodes annually at the improved productivity rate, which is 1.6 times the throughput of the old line. However, only 22,000 pounds are now being consumed, a savings of 26%.

Benefit Analysis
Metal savings
7,800 lbs. copper @$1.20/lb. = $9,360 / year

Operating cost reduction
Estimated line operating cost reduction = $15,000 / year

Total annual savings
$24,360

Payback
The system cost was recovered in less than twelve months. Other intangible benefits include:
- Decrease in corrosive deterioration of process equipment
- Reduced demand on ventilation systems
- Improved on-time deliveries
- Lower brightener consumption

In addition, the plating line personnel at United Electronics can now enjoy cleaner air, free of acid mist.

Case Study: Triad Circuits
When market forces and strained production capacity combined to hamper Triad Circuits' ability to meet their customer delivery requirements, the management of this Round Lake, Illinois manufacturer of printed circuit boards faced some challenging decisions.
They realized that in order to stay competitive and grow their business, they needed to increase productivity. The two major "pinch points" in their operation were identified as electroplating and Liquid Photoimagable Solder Mask (LPI). However, they discovered that the cost to automate both areas was prohibitive. Also, the plating area had limited room for expansion.

The first step in the plan to increase production was to design a high speed plating tank. A new 1,000 gallon tank was constructed and an existing 500 gallon tank was modified to a high speed plating tank with 800 gallons. The remaining tanks were removed. Total gallonage of copper solution was reduced from 2,100 gallons to 1,800 gallons. However, soon after the installation, the production rate from the electrolytic copper plate doubled!

There are several reasons for this seeming wizardry – first, the new tank was designed to accommodate two (2) 18" x 24" panels per rack, "over and under" vs. the one deep construction of the older tanks. This was made possible by installing a simple manual hoist over the tanks. Second, Triad Circuits installed eductor agitation systems consisting of a pump and eductor nozzles strategically placed in the tank to optimize the volume and velocity of solution that flows across the board surface. The theory behind this is that the solution movement will sweep away the spent cathodic film, which is saturated with hydrogen gas, and continuously replace it with a fresh cathodic film, rich with ionic copper for deposition. Eductors enhance the deposition by creating a venture like effect in the holes. This allows faster plating from higher current densities.

Another benefit of eductor agitation systems worth noting is that the fumes from the acid copper tanks have been reduced significantly due to the combination of less chemical surface area from the smaller number of plating tanks, as well as the elimination of the air agitation.

Performance Improvements Reported In Processes Using Eductor Technology
- Reduced noxious fumes above the tank that consequently improves the conditions for tank side personnel. The life of auxiliary equipment around the tank is also extended, as the equipment is far less prone to corrosion.
- Reduced evaporation of chemicals
- Improved solution conductivity generating power savings of up to 25%
- Reduced brightener/additive consumption
- Improved distribution leading to metal savings
- Cleaners operating at lower temperatures
- Reduction in gas pitting

- Improves filtration, as particulates do not settle
- Improved LCD throwing power
- Better/Faster etching and resist stripping with direct impingement
- **FASTER PLATING AT LOWER COST**

European Legislation and Eductors
In recent years European Legislators have accepted that the use of eductor agitation has a positive impact on Environmental issues. Reduced emissions above plating tanks, increased efficiency of processing and energy savings from reduced demands for heating have led to eductor agitation technology being nominated as a Best Available Technique Not at Excessive Cost (BATNEC).

Extracts from IPPC* *Guidance document S2.07*
To minimize emissions to air, recommends incorporating current technology as follows: -
- Generation of turbulence by hydraulic power and eductors

Conclusions
Today's PWB industry is more competitive than ever before. In many sectors there is a continuous drive to reduce costs, often impacting on the market value of plated components and products. Consequently, any process improvements that can reduce operating costs of surface treatments and improve quality must be considered very carefully. **Eductor Technology makes sense** - When its principles are reviewed against the criteria for agitating solutions, all of the objectives are more than satisfied.

A relatively small capital investment is required to install a system and payback can be achieved over a very short period. The environmental, process and cost benefits over air and other methods of agitation are indisputable when eductor systems are designed correctly and pump selection is appropriate. Already, there are currently over 3000 tanks on various processes operating with eductor systems in printed circuit board manufacturing facilities in the US; this number is increasing week by week.

References

1. Plating Rate Enhancement through the exploitation of Airless Eductor agitation; H Williams, Trans. Inst. Metal Finishing 2001, 79(3), B37
2. Exploitation of Eductor Agitation in Copper Electroplating; M Ward, D.R. Gabe, J.N. Crosby, Trans. IMF, 1998, 76, 121
3. Process Developments for the PWB Industry, M Ward, D.R. Gabe, Proc. IPC Expo 99 – March 1999, Long Beach, CA

IMPROVING PRINTED CIRCUIT BOARD PLATING WITH EDUCTOR AGITATION

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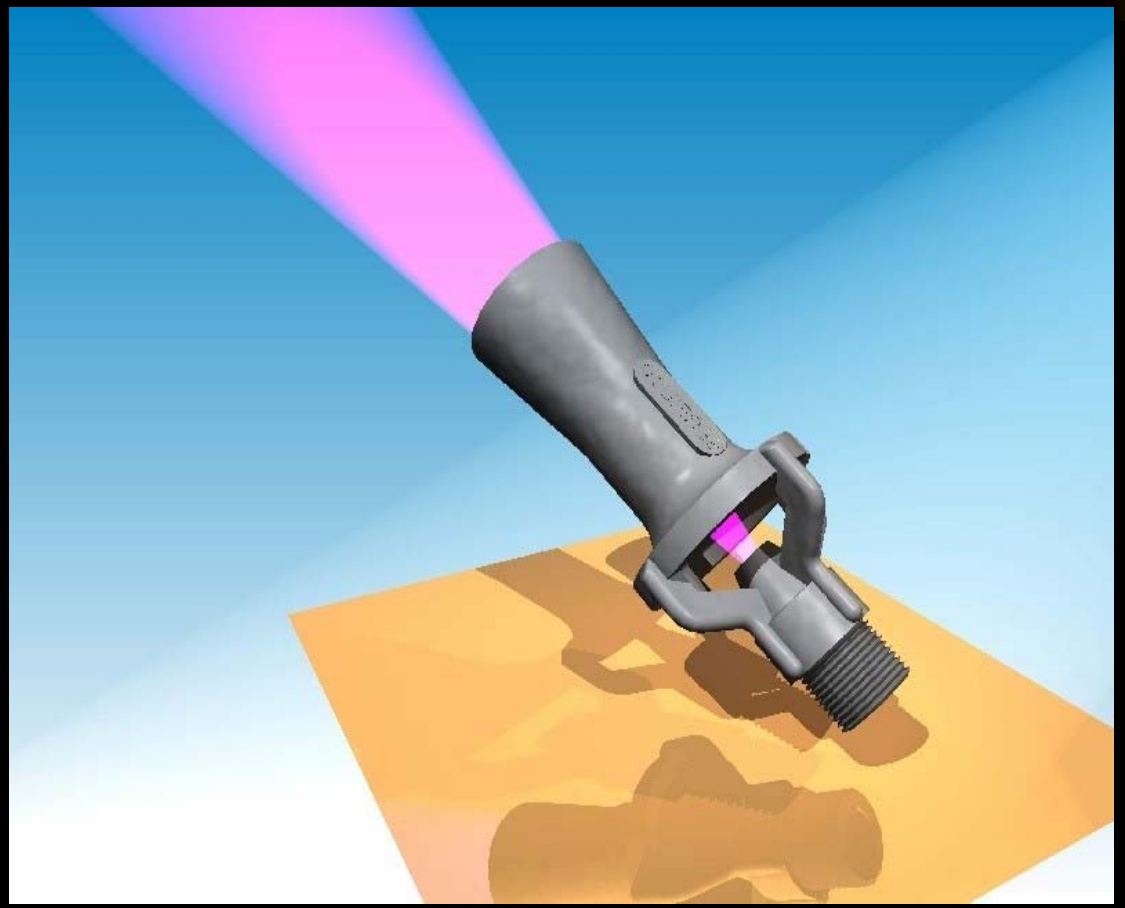

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PURPOSES OF AGITATION IN ACID COPPER PROCESSES

- To uniformly bright deposit .
- To prevent “burning”.
- Provide a constant supply of ions to the plated surface to produce more uniform coatings.
- Reduce or eliminate pitting.
- To produce the required thickness in a shorter time. (HIGH SPEED PLATING)

COMMON METHODS OF AGITATION

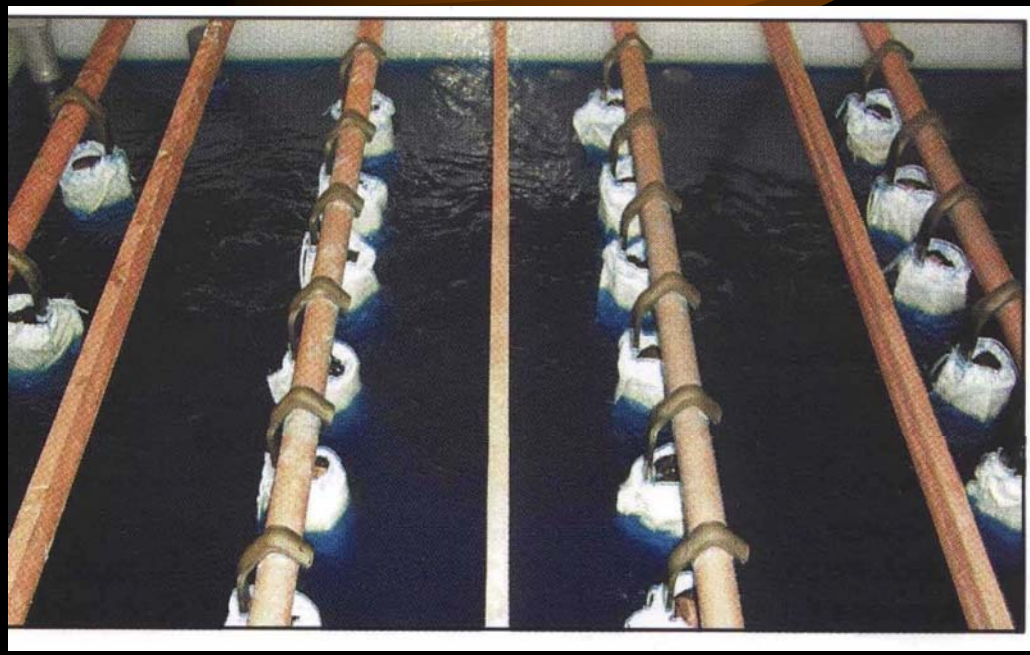
- **Air agitation.**
- **Mechanical double paddle.**
- **Pumped flow eductor agitation.**
- **Ultra-sonic agitation (in cleaners & de-greasers).**

PROBLEMS WITH AIR AGITATION

- **Creates foam and chemical mists above tank.**
- **Uneven agitation due to pipe blockage.**
- **Accelerates heat loss to atmosphere.**
- **Ineffective prevention of hot spots or chemical layering.**
- **Additive usage may increase due to oxidation.**
- **Air supply may carry oil and/or foreign matter to process tanks.**
- **Air blowers are noisy and require frequent maintenance.**

Air agitation

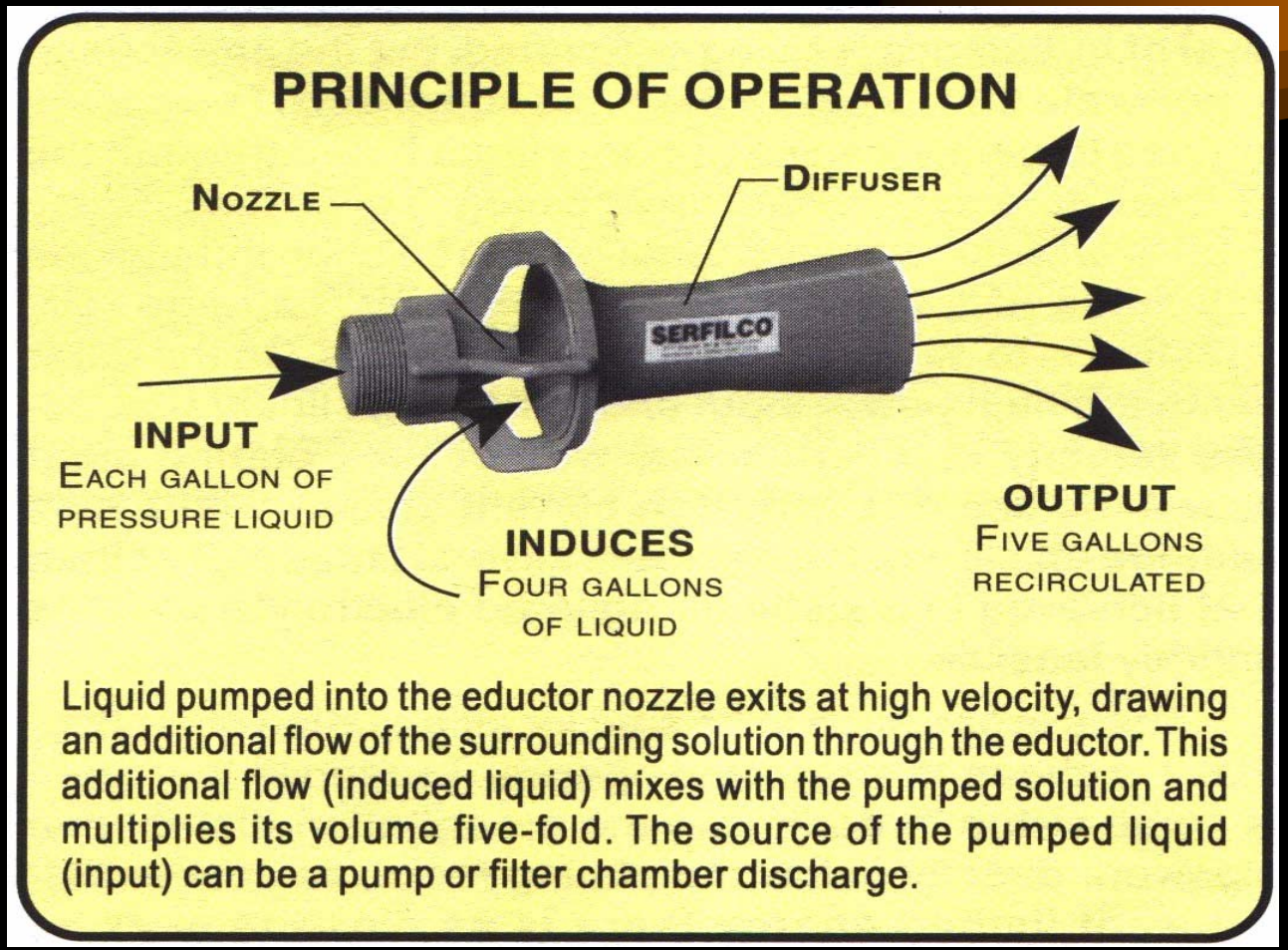
Ser-ductor® Agitation



Courtesy of Triad Circuits

CH-41

The Nozzle


PRINCIPLE OF OPERATION
NOZZLE
DIFFUSER
SERFILCO
INPUT
EACH GALLON OF PRESSURE LIQUID
INDUCES
FOUR GALLONS OF LIQUID
OUTPUT
FIVE GALLONS RECIRCULATED
Liquid pumped into the eductor nozzle exits at high velocity, drawing an additional flow of the surrounding solution through the eductor. This additional flow (induced liquid) mixes with the pumped solution and multiplies its volume five-fold. The source of the pumped liquid (input) can be a pump or filter chamber discharge.

PRINCIPLE OF OPERATION

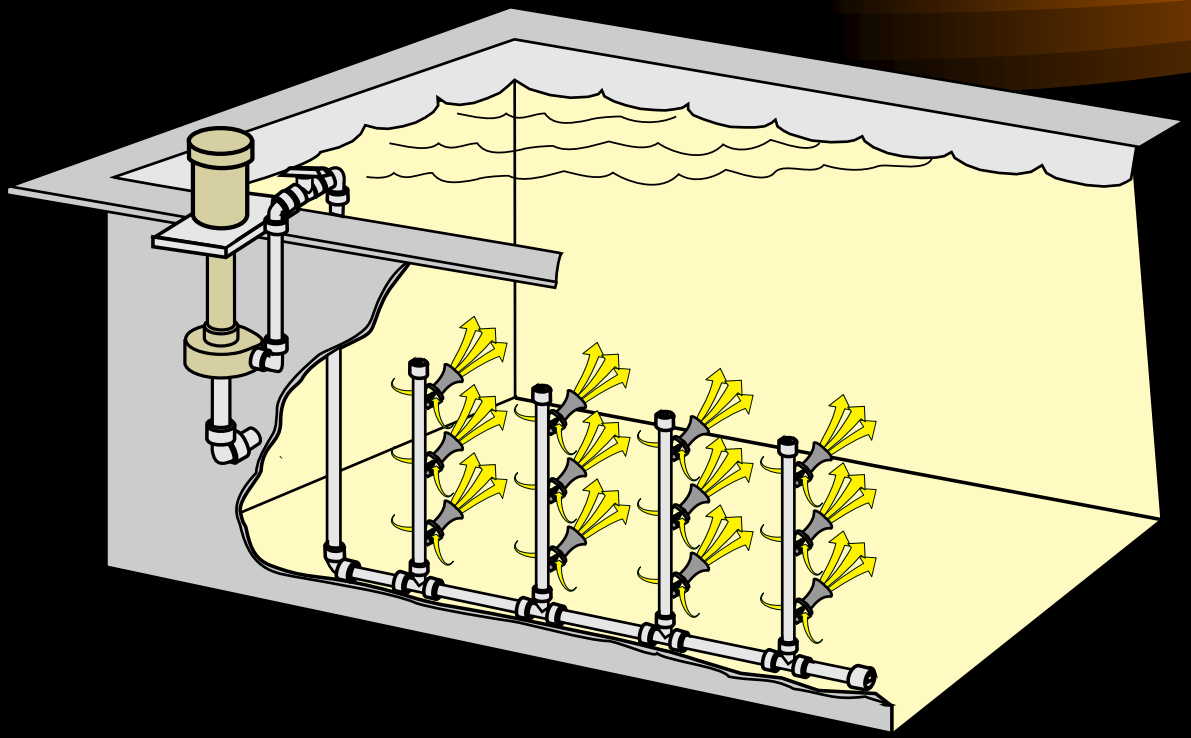
- **Eductor nozzles use the venturi principle to amplify and direct solution flow from the pump to the required area of the tank.**
- **The nozzles convert a high pressure, high velocity, low volume flow to a low pressure, low velocity, high volume flow creating a closed loop agitation of the solution in the area surrounding the nozzles.**

DESIGNING AN EDUCTOR AGITATION SYSTEM

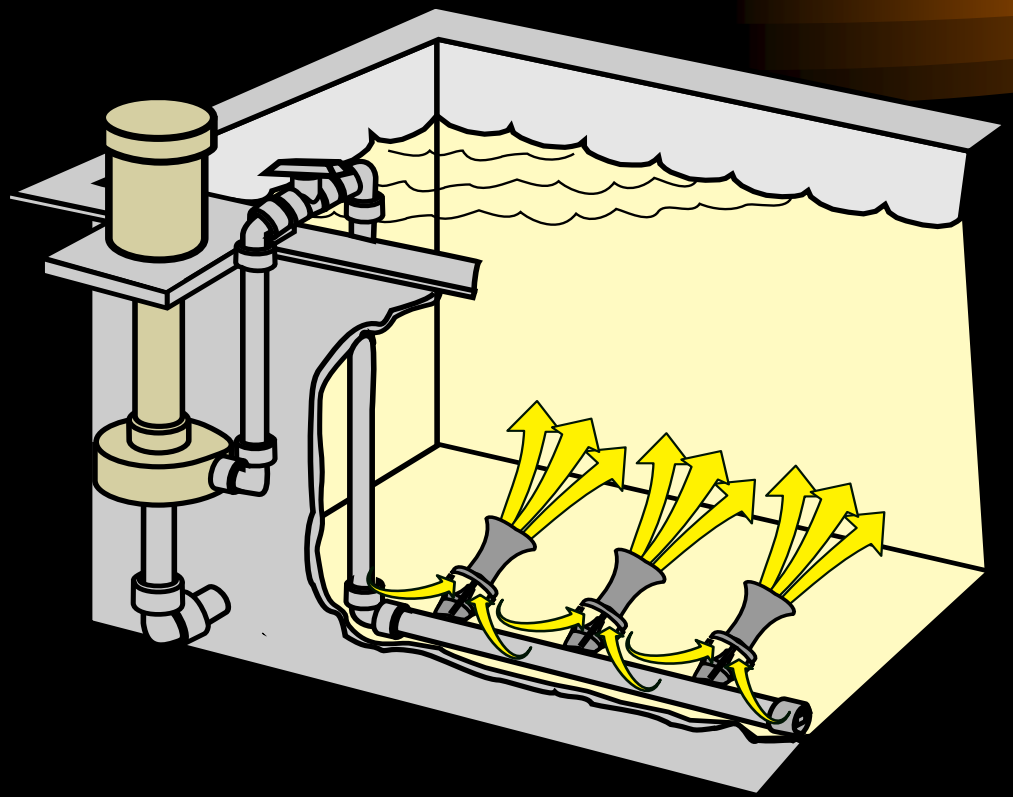
What specific type of agitation is required for the application?

1. **Direct solution impingement on the work.**
2. **Rolling agitation sweeping tank bottom.**
3. **General agitation avoiding direct impingement.**
4. **Combination of 1, 2 and 3.**

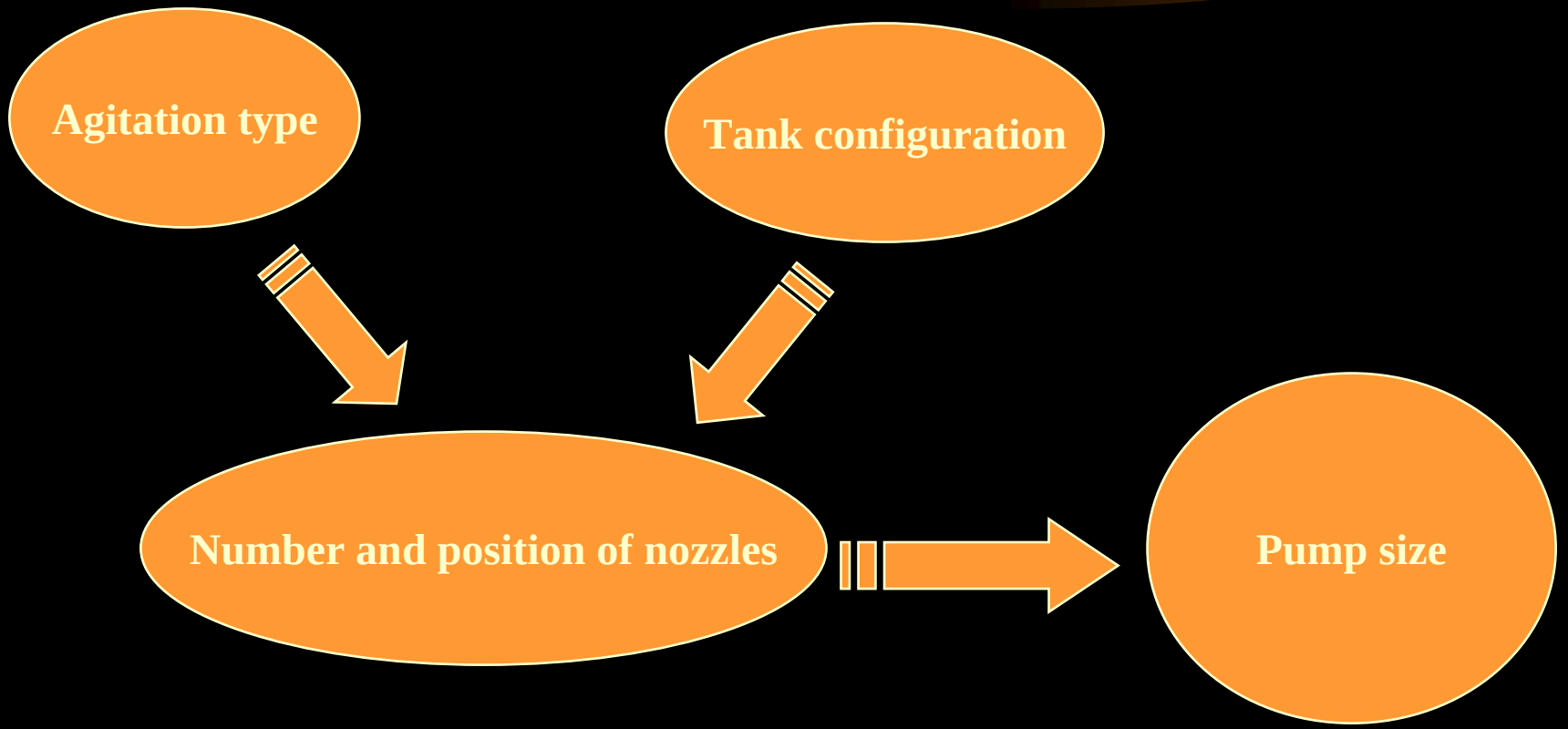
Agitation providing direct impingement



Agitation providing mixing



How to size your eductor system



Case History
Acid Copper PCB

- **Company - Triad Circuits**
- **Process - Electrolytic acid copper plating**
- **Needed to increase production capacity in order to meet customer's delivery requirements**

Results of replacing air agitation with Eductor agitation

1. **Increased productivity and yields**
2. **Improved in-hole thickness distribution**
3. **Reduced photo resist, copper anode and brightener costs**
4. **Dramatic reduction of fuming and misting**

Results – Air vs Eductors

	With air	With eductors
Current Density	13 ASF	Up to 40ASF
Through hole thickness	.001 inch to .0015 inch	.001 inch to .0012 inch
Dwell Time	90 mins	30 mins
Emissions		Reduced
Brightener usage		Reduced

AIR-FREE vs. AIR AGITATION

- **Faster plating from higher current densities**
- **Lower metal usage**
- **Savings on brightener consumption**
- **Reduction / elimination of gas pitting**
- **Heat savings**
- **Improves throw and deposit thickness in blind holes and microvias**
- **Low cost to improve productivity**

- **Airborne fume emissions and misting**
- **Bath contamination from airborne matter**
- **Particulate matter settles on tank bottom**
- **Uneven plating deposition**

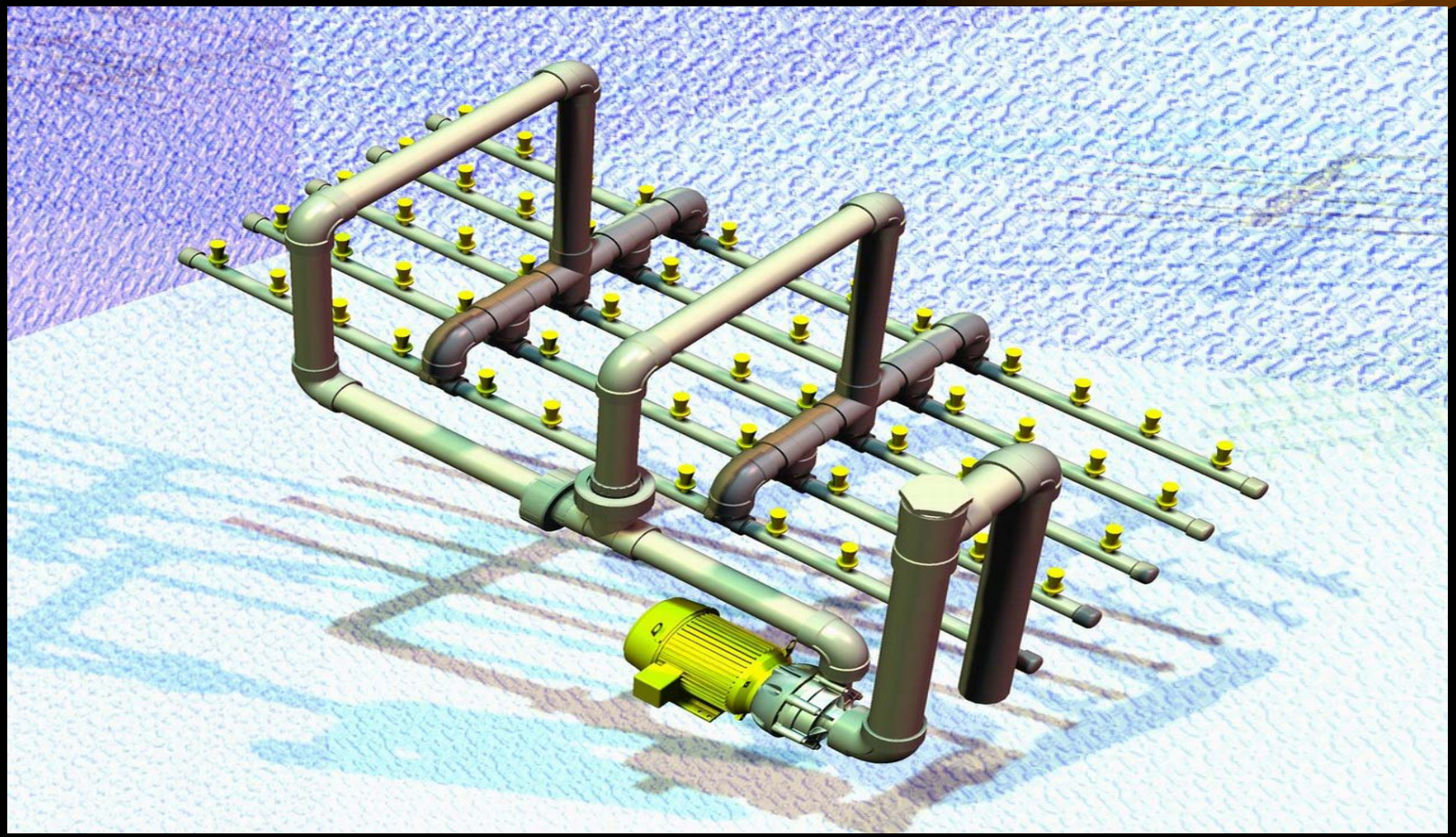
Ser-Ductor Pressure / Flow Chart

SIZE MNPT	CENTER SPACING	PSI / TDH (feet)								
		10 / 23'	15 / 35'	20 / 46'	25 / 58'	30 / 69'	35 / 81'	40 / 92'	45 / 104'	50 / 116'
		GPM								
1/4"	6 - 8"	3.5	4.0	4.5	5.5	6.0	6.5	7.0	7.1	7.2
3/8"	9 - 12"	7.5	9.2	10.7	11.9	13.1	14.1	15.0	16.0	17.0
3/4"	12 - 16"	13.5	17.0	19.0	21.0	23.0	25.0	27.0	28.0	29.0
1"	16 - 21"	21.0	25.0	29.0	33.0	36.0	39.0	42.0	45.0	47.0
1-1/2"	21 - 27"	33.0	41.0	47.0	53.0	58.0	63.0	67.0	71.0	75.0
Eff. plume length:		5.0'	7.5'	10.0'	12.5'	15.0'	17.5'	20.0'	22.5'	25.0'

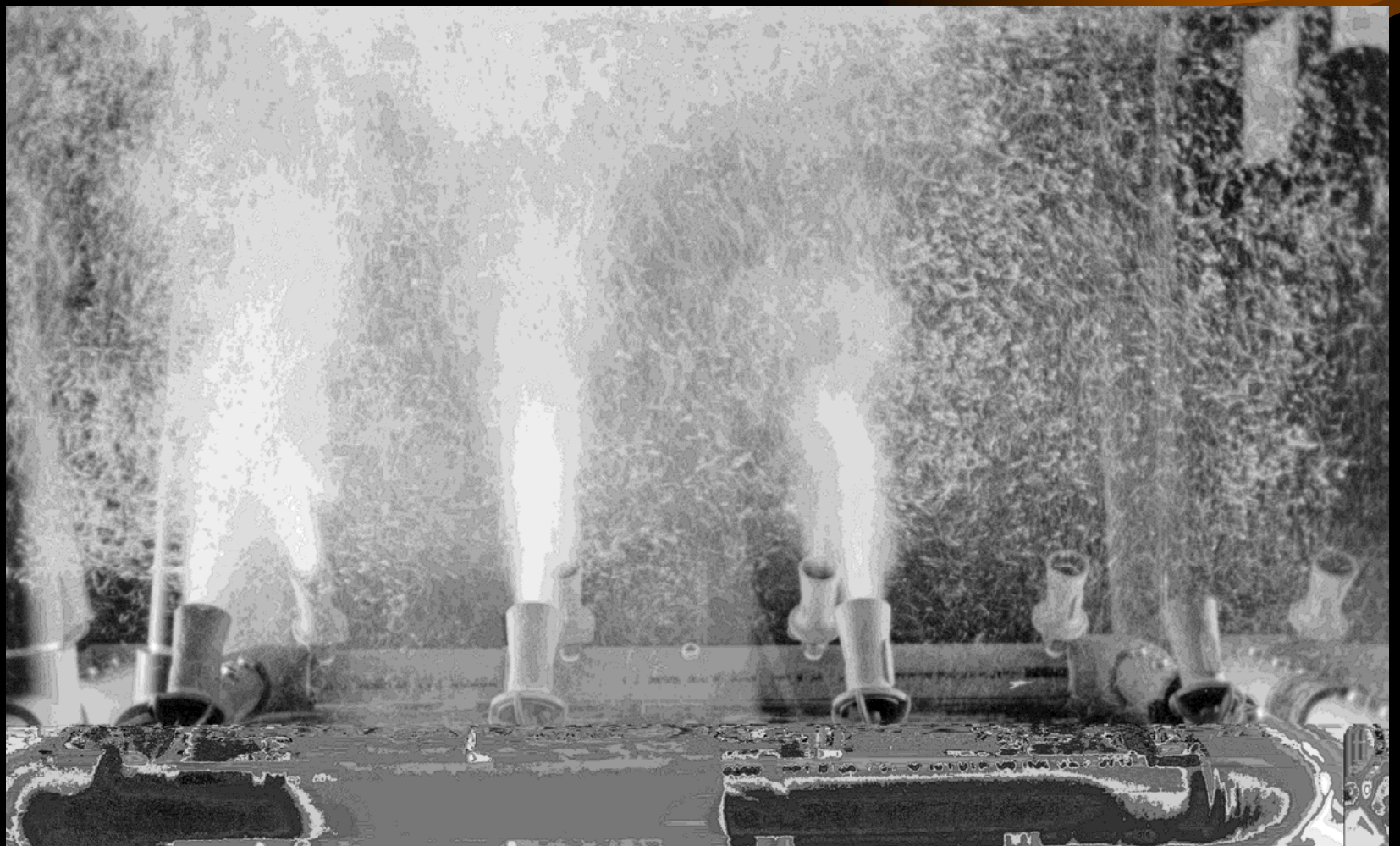
NOTE: Above values are based on Ser-Ductor input flow / PSI. Multiply by 5 for effective output flow per nozzle.

AVAILABILITY: PP – 1/4”, 3/8”, 3/4”, 1” and 1-1/2”
CPVC – 1/4”, 3/8”
PVDF – 1/4”, 3/8”, 3/4”, 1” and 1-1/2”

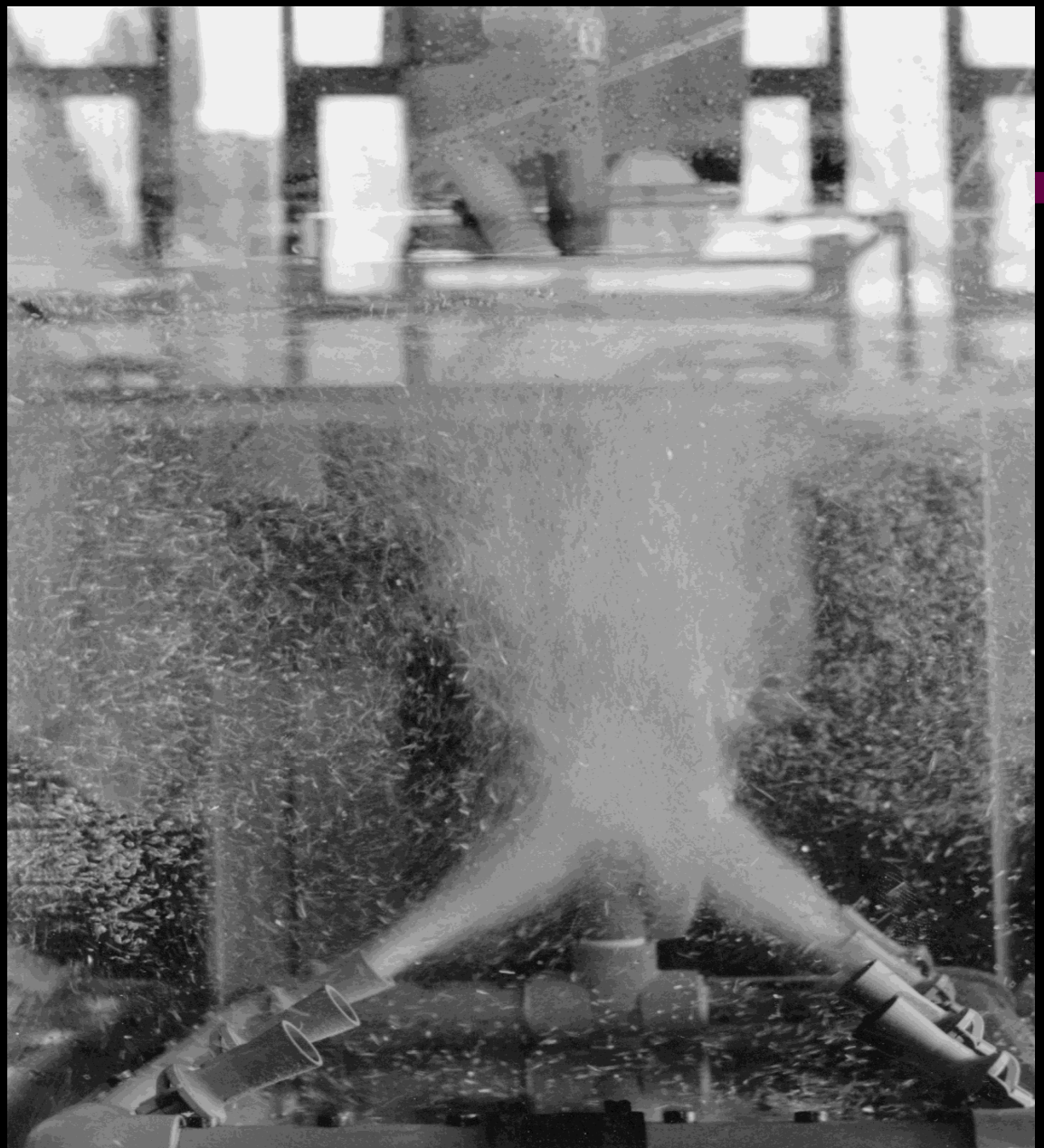
Possible eductor system for acid copper PCB plating



Eductor agitation system in action….



Eductor agitation in action….



Eductor agitation systems provide…

- **Airborne fume emission reduction up to 90%.**
- **Reduction or elimination of “mouse bites”.**
- **Savings on additive consumption up to 20%.**
- **Reduction or elimination of gas pitting.**
- **More uniform coatings.**
- **Elimination of temperature stratification.**
- **Faster plating - permits higher current density.**

Recommendations…

- **Consider the application very carefully.**
- **TEST TANK - install an eductor system on one of your process tanks.**
- **Seek design advice from a company that specializes in eductor systems.**