PRODUCTION OF PARABOLOIDAL SILVER-COATED MIRRORS FROM

FLOAT GLASS FOR SOLAR APPLICATION

By

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A Thesis Submitted to The Honors College

In Partial Fulfillment of the Bachelors degree
With Honors in

Chemical Engineering

THE UNIVERSTIY OF ARIZONA

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Approved by:

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Abstract:

A 100 mirror a day prodiction line for the production of silver coated paraboloidal mirrors from float glass was evaluated. The mirrors are highly specialized and to be use in a Concentrated Photovolateic sustem. The process takes flat pieces of float glass and slumps them into paraboloids. The paraboloids are cleaned, sensitized, and silvered. The siler layer is protected by three layers of coating- one of copper and two of paint. During the design, safety and environmental conserns are mitigated through equiptment, chemical, and process choices. The economic value of this project yeilding a Net Present Value $1.5 million over a 20-year life span as well as the saftly and environmetnal impacts were evaluated. Despite the low projections, it is recommened to build this plant due the the niche it will fill in the solar energy market.

STATEMENT OF ROLES AND RESPONSIBILITIES

This thesis project was a result of a group effort from four Chemical Engineering Seniors – Elizabeth Forhan, Safatul Islam, Cassandra Messina, and Thomas Zavada. The project consisted of both laboratory work and theoretical plant design. Each member performed several roles and responsibilities, all of which are described below.

Tom Zavada was responsible for the entirety of the Equipment sections, including Equipment Tables and the corresponding calculations and sizing. This included sizing and temperature calculations necessary for the slumping furnace, the most important piece of equipment for the process. Also included were the power calculations for the pieces of equipment, rationale behind specific equipment choices, and the chemical flow rates used associated with each piece of equipment. Tom also contributed to pricing estimations for some pieces of equipment. For Process Rationale, Tom was involved in writing the Paint Backing section discussing the use of heat cured paints as opposed to other industry standards. For the appended lab report, Tom contributed the equipment list and procedures for Experiment 1.

Elizabeth Forhan was responsible for the entirety of the Environmental Analysis section of the report. In an effort to develop a thorough life cycle analysis of the mirror production plant, she examined many of the specific chemical and waste streams in the process, along with alternative chemicals. In particular, Elizabeth took the lead in studying the N-methyl-D-glucamine reducer, the cerium oxide polishing agent, and the silvering waste water. Her analysis led her to discussions with both Pima County Waste Water Treatment and University of Arizona Risk Management in order to figure out how to dispose of chemical wastes. Elizabeth evaluated the entire solar concentrating system in her life cycle analysis to produce a more detailed understanding of environmental impact. In addition to this section of the report, Elizabeth worked diligently with Safatul to test the spray silvering process during multiple lab sessions. Elizabeth also contributed to the mass balances and was responsible for four of the seven sections of Rationale for Process Choice. In addition, Elizabeth wrote the results and conclusions for the overall report. For the appended lab report, Elizabeth contributed to the equipment lists and procedures as well as wrote the results and conclusions.

Safatul Islam was responsible for much of the process design and process calculations, all of which led to the creation of the Process Flow Diagram and Stream Table. Safatul wrote up the Process Description section of the report and wrote the Location Rationale and Production scale portions of the process rationale. Safatul was also responsible for the Economic Analysis of the plant. This involved selecting both the raw materials and equipment, including large quantity of specialized sprayers, furnaces, and curtain coaters that required vendor pricing. In his Economic Analysis of the plant, Safatul determined the financial sensitivity of multiple factors, particularly the production rate and the mirror price. He also calculated the effects of government subsidies in the solar sector. In addition to the report, Safatul worked to set up and perform the silvering experiments. This included ordering the necessary chemicals and supplies and finding an empty lab with fume hood where the experiments could be executed. He also took reflectivity measurements of the mirrors after silvering. For the appended lab report, Safatul wrote the reflectivity testing procedure and contributed to the results and conclusions.

Cassandra Messina began researching the process early along with Safatul to identify the necessary components and order of processes. She was in charge of writing the Introduction, including the Overall Goal, Background Information, and Market Research. Cassandra also was responsible for the entirety of the Safety Statement. Her efforts included creating a Job Hazard Analysis for the process and working closely with University of Arizona Safety Coordinators to identify necessary precautions. Cassandra also did significant work aiding Safatul with process calculations and mass balances that lead to the process flow diagram and stream tables. For the appended lab report, Cassandra did specific research into the chemistry behind the process, including the sensitizing and silver reduction oxidation reaction. For the written report, Cassandra also wrote the Summary and was heavily involved in formatting and compiling the final product.

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1 Introduction

1.1 Overall Goal

The overall goal of the following report is to discuss a proposed process that creates paraboloidal mirrors from flat float glass, and to examine the viability of that process given economic, environmental, and safety considerations. The mirrors are to be used as reflectors in solar concentrating systems that convert sunlight to usable energy. For solar application, the mirrors must be highly reflective, reflecting at least 95% of all visible light. The system will be outdoors, so it is also necessary for the mirrors to be durable and weather resistant for long-term use. The production process is designed to fulfill the requirements of REhnu Inc. a solar technologies company based in Tucson, Arizona that has collaborated with the Steward Observatory Solar Lab at the University of Arizona. The proposed plant will therefore be located in Tucson and must be operational for a twenty-year period.

1.2 Description of What is Being Made and Current Market Information

Due to the ever-growing focus on the environment and sustainability in today's society, renewable energy has become increasingly popular. Because of this, scientists across the world have been exploring renewable energy systems with fervor. Solar power systems are amongst the most popular types of renewable energy. In a solar power system, solar radiation is collected and converted into a more usable form of energy, usually heat or electricity. In an effort to add robustness to this process, solar radiation is often concentrated as a preliminary step. There are two main technologies used to convert that radiation;, heat engines (concentrated solar power) or photovoltaic systems. Concentrated solar power (CSP) systems concentrate a large area of the sun's energy into a collector. There, the heat produced is converted to electricity through a generator or thermochemical reaction. The additional step required to convert the heat into electricity decreases the efficiency of the process overall. On the other hand, concentrated photovoltaic systems (CPV) absorb the sun's energy into solar cells and use it to excite electrons, which carry the energy as electrical charge. This is often accomplished with a network of solar panels, which can take up a relatively large area for the power produced.

However, the mirror array that is the subject of this study concentrates the sunlight to a focal point, where a solar collector converts the radiation into electricity. This significantly reduces the required area, while maintaining the power output.

REhnu's goal is to design and produce a CPV system that can generate power at a cost of less than one dollar per watt. It is important to create renewable energy in an affordable range so that it can be competitive with non-renewable energies, such as petroleum-based fuels. A crucial part of this effort comes from having high quality solar mirrors – mirrors that are both highly durable and highly reflective. The durability ensures a long life span that will provide monetary benefits in the long term. Each system requires eight identical solar mirrors, as can be seen in Figure 1.1 below. The mirrors for this system must meet certain requirements to be suitable for the REhnu concentrating unit. The mirrors must be 4 mm thick and 1.65 m by 1.65 m in length and width. They are of a paraboloidal (or dish) shape, which is highly specialized for this system. The paraboloidal shape increases efficiency because it is able to concentrate the sunlight to a point, rather than to a line as the more common parabolic reflectors do. This makes it possible to reduce the size of the concentrating unit and still collect the same amount of energy. The mirror shape is accomplished through glass slumping. For solar purposes, the mirror must be coated with silver as opposed to aluminum because it is the most reflective mirroring chemical. Silver has an average reflectivity of 98%, whereas aluminum has an average reflectivity of just 92% (Czanderna et al. 10). The mirrors must be at least 95% reflective to concentrate the sunlight to an effective range for the CPU, so aluminum is inadequate. Additionally, the mirrors must be durable for long-time use outdoors. In this design, the proposed facility is capable of making 100 such mirrors per day.

Figure 1.1. REhnu Generation III mirror array.

In today's market, flat plate photovoltaic (PV) systems make up 98% of the worldwide solar share (Concentrated Photovoltaics 3). However, CPV systems have benefits that make fast scale-up appealing. For instance, these systems have higher capacity factors than their solar panel counterparts, and therefore produce the same amount of electricity with reduced water and land requirements. In fact, it is estimated that by 2016, CPV may represent up to 27% of the US photovoltaic solar market (Concentrated Photovoltaics 3). This growing market indicates a growing demand for CPV systems such as REhnu's. Another advantage to CPV technology is the relatively low material costs. Material costs for REhnu's system reflect this, at just $0.70 per watt compared to the $2 per watt costs of flat plate photovoltaic systems (Concentrated Photovoltaics 3). The cost for the individual solar mirrors is a more difficult comparison because of the highly specialized shape. RioGlass Solar Inc., located in Surprise, Arizona, produces similarly sized parabolic mirrors that are made and sold at $85 per mirror (RioGlass 2013). However, these mirrors are simply bent to get their more generic, parabolic shape. They are not slumped or meant to be part of a specialized system like REhnu's design. RioGlass also produces at a very high production rate, outputting nearly one mirror every 20 seconds. This drastically drives down production cost per mirror, allowing for the cheaper sale. At this rate, RioGlass has out produced the demand, and their facilities are currently in hibernation. It is critical for REhnu's future that there is adequate balance of production rate and demand.

1.3 Project Premises and Assumptions

1.3.1 Project Premises

The mirrors created are to be part of the larger CPV system designed by REhnu, but only the mirror production aspect of that system is being considered in the plant design. The process starts with sheets of flat float glass, precut to the desired dimensions. The glass is rinsed and then slumped in a furnace to the desired shape. From there, the glass goes through quality testing, rinsing, cleaning, sensitizing, and silvering before a series of protective paint backings are applied. To match the REhnu location, the plant is designed to operate in Tucson, Arizona. The final plant design is largely based on information from various papers, textbook correlations, research and prior work performed by REhnu employees, and an understanding of mass and energy balances. Likewise, economic calculations and conclusions are based on cost equations that can be found in Seider et al. (2009), purchase costs, and other sources.

The environmental impact of the plant as well as safety considerations are based on data that compares well defined factors such as resource consumption, toxicity, corrosivity, and flammability. This data can largely be found in material safety data sheets (MSDS) and technical data sheets.

1.3.1 Assumptions

- With the current market, all 100 mirrors per day will be sold.
- The plant is open 8 hours a day, 260 days per year.
- Mirrors are only transported within a 100-mile radius.
- The plant employs six operators.
- The combined corporate tax rate for federal and state is 41.5%.
- An interest rate of 15% is used for economic calculations.
- The depreciation model used is based on the MACRS 7-Year Plant Life Model.
- For pump calculations, head pressure is always 100 ft.
- Pump efficiency is assumed to be 45%.

- Transfer efficiency for the silver spray and sensitizer is 80%.
- The mass coming off the mirrors in the water rinse streams is negligible compared to the mass of the water.
- Assume that all paint is either deposited onto the glass or recycled.
- The environmental waste calculations assume a worst-case scenario; no silver is deposited onto the glass.

2 Process Description, Rationale, and Optimization

2.1 Process Overview

Solar concentrator mirrors are produced by slumping float glass into a paraboloidal shape and then adding layers of silver, copper, and protective paint. The process described is generated by scaling up and modifying laboratory experiments conducted by current and former students and employees at the Steward Observatory Solar Lab. These experiments are described in Appendix A. Figure 2.1 presents a block flow diagram of this overall process. The proposed plant consists of two main sections – slumping and silvering. Flat float glass, 1.65 m by 1.65 m, is purchased and then sent through a furnace where it is slump molded into the desired shape. The paraboloidal piece then proceeds to a wet process silvering mechanism, where the convex surface of the glass is coated with silver and then protected with paint layers. Throughout the whole process, multiple rinsing stages are implemented to ensure the highest quality. The final product is a fully silvered and coated, paraboloidal mirror with high reflectivity and long-term durability.

2.2 Block Flow Diagram

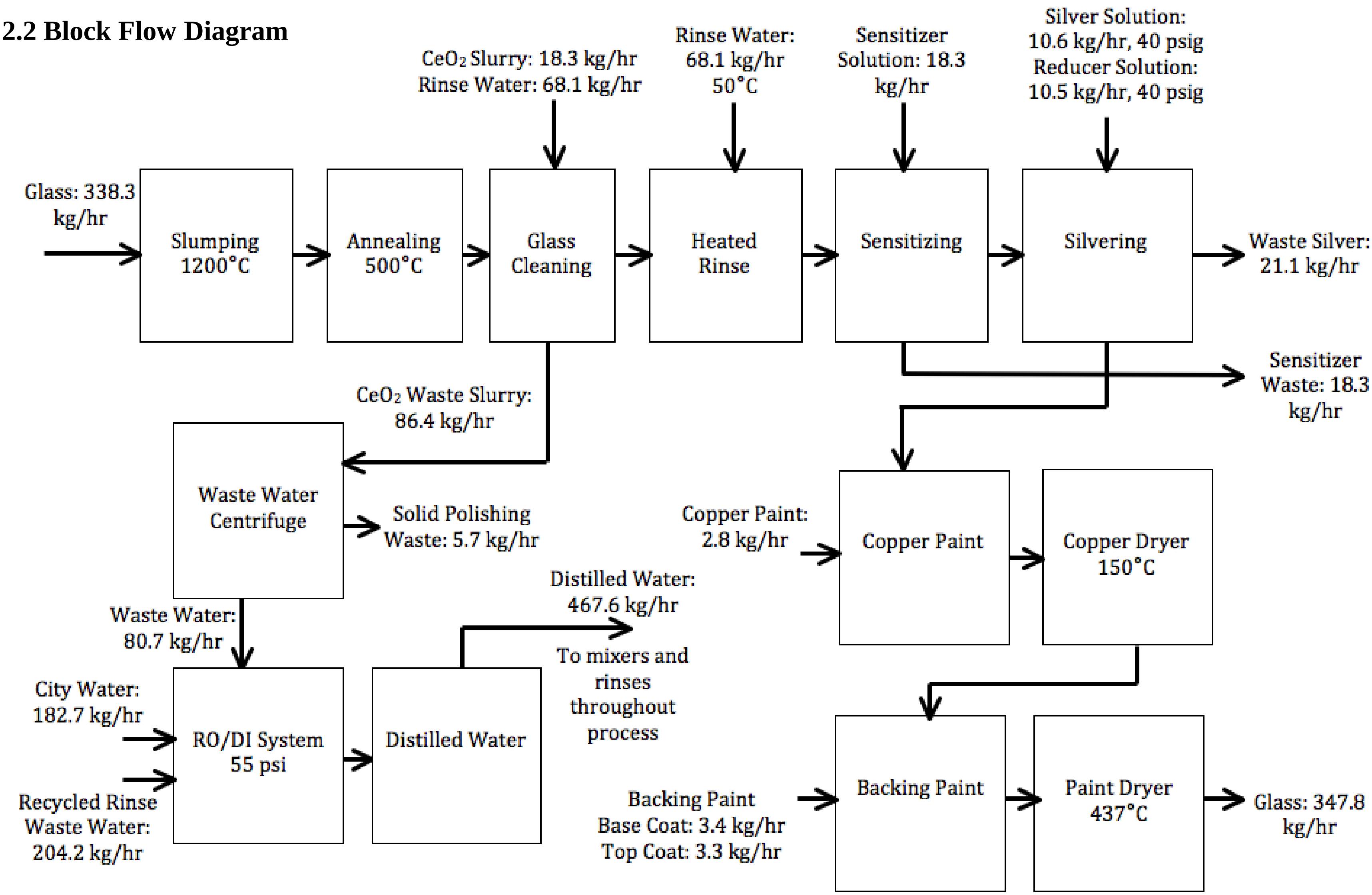

Figure 2.1. Block flow diagram for glass silvering process.

2.3 Process Flow Diagram

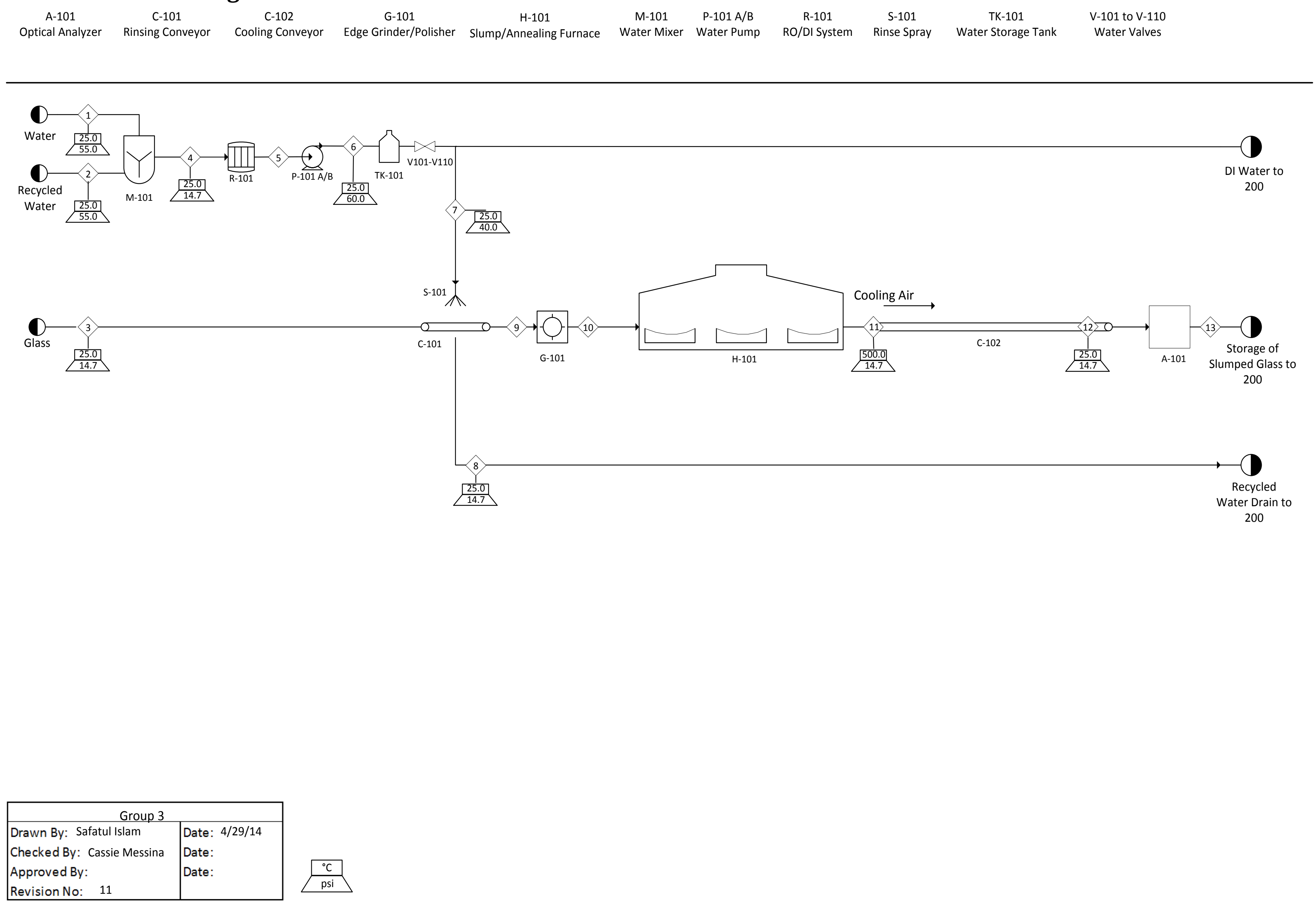

Figure 2.2a. Room 1 of process flow diagram for glass silvering.

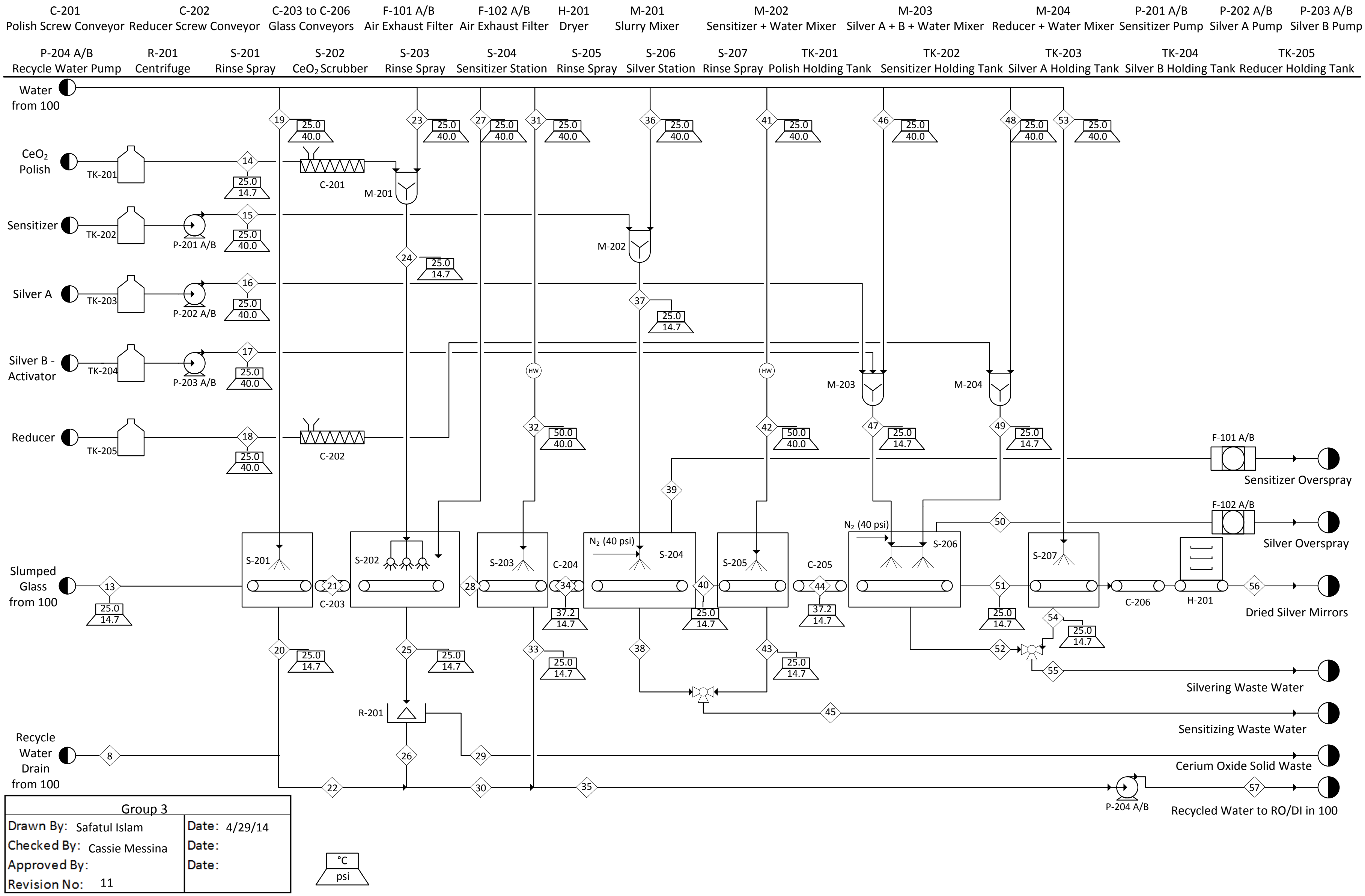

Figure 2.2b. Part 1 of Room 2 of process flow diagram for glass silvering.

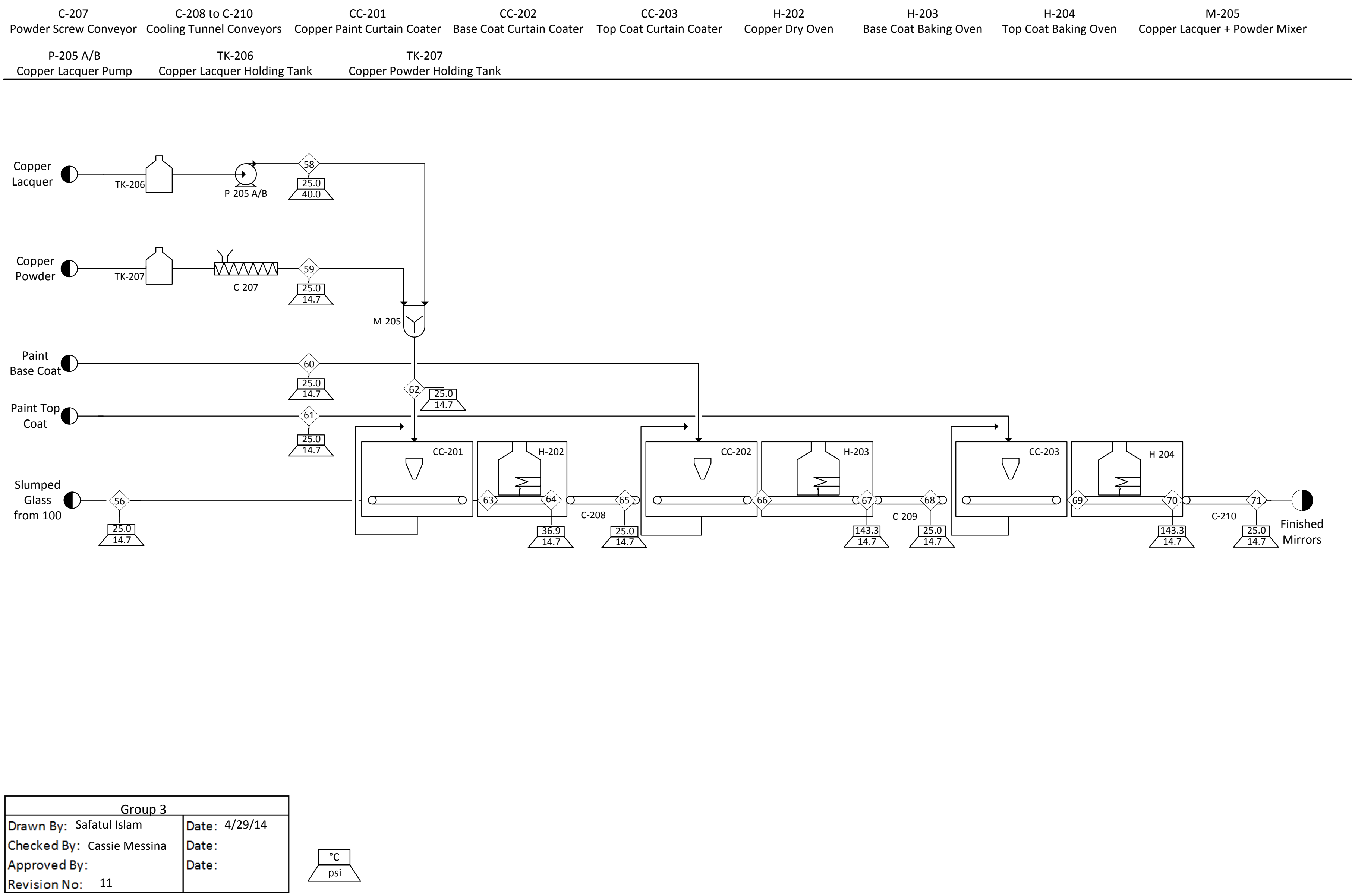

Figure 2.2c. Part 2 of Room 2 of process flow diagram for glass silvering.

2.4 Steam Table

Table 2.1. Stream table for glass silvering process.

Stream Number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Temperature (°C)	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
Pressure (psi)	55.0	55.0	14.7	14.7	14.7	60.0	40.0	14.7	14.7
Vapor Fraction	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mass Flow (g/min)	3045.8	4747.5	5637.5	7793.3	7793.3	7793.3	1134.4	1134.4	5637.5
Component Mass Flow									
Glass	0.0	0.0	5637.5	0.0	0.0	0.0	0.0	0.0	5637.5
Distilled Water	0.0	0.0	0.0	0.0	0.0	0.0	1134.4	1134.4	0.0
Cerium Oxide	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sensitizer	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Propyl Alcohol	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hydrochloric Acid	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Stannous Chloride	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Water	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Peacock Silver A	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Silver Diammine	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ammonium Hydroxide	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Water	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Peacock Solution B	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sodium Hydroxide	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ammonium Hydroxide	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N-methylglucamine	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Copper Coating	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Copper Lacquer	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Copper Powder	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Base Coat Paint	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Top Coat Paint	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Silver	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Recycle Water	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1134.4	0.0

Stream Number	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
Temperature (°C)	25.0	500.0	25.0	0.0	25.0	25.0	25.0	25.0	25.0
Pressure (psi)	14.7	14.7	14.7	0.0	14.7	14.7	14.7	14.7	14.7
Vapor Fraction	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mass Flow (g/min)	5637.5	5637.5	5637.5	0.0	5637.5	94.5	18.1	6.8	6.5
Component Mass Flow									
Glass	5637.5	5637.5	5637.5	0.0	5637.5	0.0	0.0	0.0	0.0
Distilled Water	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cerium Oxide	0.0	0.0	0.0	0.0	0.0	94.5	0.0	0.0	0.0
Sensitizer	0.0	0.0	0.0	0.0	0.0	0.0	18.1	0.0	0.0
Propyl Alcohol	0.0	0.0	0.0	0.0	0.0	0.0	3.6	0.0	0.0
Hydrochloric Acid	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.0	0.0
Stannous Chloride	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.0	0.0
Water	0.0	0.0	0.0	0.0	0.0	0.0	12.7	0.0	0.0
Peacock Silver A	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.8	0.0
Silver Diammine	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.1	0.0
Ammonium Hydroxide	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0
Water	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.1	0.0
Peacock Solution B	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.5
Sodium Hydroxide	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7
Ammonium Hydroxide	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
Other	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.5
N-methylglucamine	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Copper Coating	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Copper Lacquer	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Copper Powder	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Base Coat Paint	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Top Coat Paint	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Silver	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Recycle Water	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Stream Number	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**
Temperature (°C)	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
Pressure (psi)	40.0	14.7	14.7	14.7	40.0	14.7	14.7	14.7	40.0
Vapor Fraction	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mass Flow (g/min)	1134.4	1134.4	5637.5	2268.8	210.0	304.5	1438.9	1344.4	1134.4
Component Mass Flow									
Glass	0.0	0.0	5637.5	0.0	0.0	0.0	0.0	0.0	0.0
Distilled Water	1134.4	1134.4	0.0	2268.8	210.0	210.0	1344.4	1344.4	1134.4
Cerium Oxide	0.0	0.0	0.0	0.0	0.0	94.5	94.5	0.0	0.0
Sensitizer	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Propyl Alcohol	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hydrochloric Acid	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Stannous Chloride	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Water	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Peacock Silver A	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Silver Diammine	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ammonium Hydroxide	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Water	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Peacock Solution B	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sodium Hydroxide	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ammonium Hydroxide	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N-methylglucamine	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Copper Coating	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Copper Lacquer	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Copper Powder	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Base Coat Paint	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Top Coat Paint	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Silver	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Recycle Water	0.0	1134.4	0.0	2268.8	0.0	0.0	0.0	1344.4	0.0

Stream Number	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**
Temperature (°C)	25.0	25.0	25.0	25.0	50.0	25.0	30.0	25.0	25.0
Pressure (psi)	14.7	14.7	14.7	40.0	40.0	14.7	14.7	14.7	40.0
Vapor Fraction	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mass Flow (g/min)	5637.5	94.5	3613.1	1134.4	1134.4	1134.4	5637.5	4747.5	438.7
Component Mass Flow									
Glass	5637.5	0.0	0.0	0.0	0.0	0.0	5637.5	0.0	0.0
Distilled Water	0.0	0.0	3613.1	1134.4	1134.4	1134.4	0.0	4747.5	438.7
Cerium Oxide	0.0	94.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sensitizer	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Propyl Alcohol	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hydrochloric Acid	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Stannous Chloride	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Water	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Peacock Silver A	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Silver Diammine	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ammonium Hydroxide	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Water	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Peacock Solution B	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sodium Hydroxide	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ammonium Hydroxide	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N-methylglucamine	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Copper Coating	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Copper Lacquer	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Copper Powder	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Base Coat Paint	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Top Coat Paint	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Silver	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Recycle Water	0.0	0.0	3613.1	0.0	0.0	1134.4	0.0	4747.5	0.0

Stream Number	**37**	**38**	**39**	**40**	**41**	**42**	**43**	**44**	**45**
Temperature (°C)	25.0	25.0	25.0	25.0	25.0	50.0	25.0	30.0	25.0
Pressure (psi)	14.7	14.7	14.7	14.7	40.0	40.0	14.7	14.7	14.7
Vapor Fraction	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0
Mass Flow (g/min)	456.8	365.4	91.4	5637.5	1134.4	1134.4	1134.4	5637.5	1499.8
Component Mass Flow									
Glass	0.0	0.0	0.0	5637.5	0.0	0.0	0.0	5637.5	0.0
Distilled Water	438.7	350.9	87.7	0.0	1134.4	1134.4	1134.4	0.0	1485.3
Cerium Oxide	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sensitizer	18.1	14.5	3.6	0.0	0.0	0.0	0.0	0.0	14.5
Propyl Alcohol	3.6	2.9	0.7	0.0	0.0	0.0	0.0	0.0	2.9
Hydrochloric Acid	0.9	0.7	0.2	0.0	0.0	0.0	0.0	0.0	0.7
Stannous Chloride	0.9	0.7	0.2	0.0	0.0	0.0	0.0	0.0	0.7
Water	12.7	10.1	2.5	0.0	0.0	0.0	0.0	0.0	10.1
Peacock Silver A	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Silver Diammine	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ammonium Hydroxide	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Water	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Peacock Solution B	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sodium Hydroxide	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ammonium Hydroxide	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N-methylglucamine	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Copper Coating	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Copper Lacquer	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Copper Powder	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Base Coat Paint	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Top Coat Paint	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Silver	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Recycle Water	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Stream Number	**46**	**47**	**48**	**49**	**50**	**51**	**52**	**53**	**54**
Temperature (°C)	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
Pressure (psi)	14.7	40.0	14.7	14.7	14.7	14.7	40.0	14.7	14.7
Vapor Fraction	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0
Mass Flow (g/min)	176.8	174.9	175.2	35.4	5637.9	141.1	1134.4	1134.4	176.8
Component Mass Flow									
Glass	0.0	0.0	0.0	0.0	5637.5	0.0	0.0	0.0	0.0
Distilled Water	163.4	174.9	174.9	0.0	0.0	130.7	1134.4	1134.4	163.4
Cerium Oxide	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sensitizer	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Propyl Alcohol	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hydrochloric Acid	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Stannous Chloride	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Water	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Peacock Silver A	6.8	0.0	0.0	0.0	0.0	5.5	0.0	0.0	6.8
Silver Diammine	2.1	0.0	0.0	0.0	0.0	1.6	0.0	0.0	2.1
Ammonium Hydroxide	0.7	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.7
Water	4.1	0.0	0.0	0.0	0.0	3.3	0.0	0.0	4.1
Peacock Solution B	6.5	0.0	0.0	0.0	0.0	5.2	0.0	0.0	6.5
Sodium Hydroxide	0.7	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.7
Ammonium Hydroxide	0.3	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.3
Other	5.5	0.0	0.0	0.0	0.0	4.4	0.0	0.0	5.5
N-methylglucamine	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0
Copper Coating	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Copper Lacquer	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Copper Powder	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Base Coat Paint	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Top Coat Paint	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Silver	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0
Recycle Water	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Stream Number	**55**	**56**	**57**	**58**	**59**	**60**	**61**	**62**	**63**
Temperature (°C)	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
Pressure (psi)	14.7	14.7	55.0	40.0	14.7	14.7	14.7	14.7	14.7
Vapor Fraction	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mass Flow (g/min)	1275.4	5637.9	4747.5	53.6	10.5	56.2	55.8	46.8	5684.6
Component Mass Flow									
Glass	0.0	5637.5	0.0	0.0	0.0	0.0	0.0	0.0	5637.5
Distilled Water	1265.1	0.0	4747.5	0.0	0.0	0.0	0.0	0.0	0.0
Cerium Oxide	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sensitizer	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Propyl Alcohol	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hydrochloric Acid	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Stannous Chloride	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Water	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Peacock Silver A	5.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Silver Diammine	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ammonium Hydroxide	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Water	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Peacock Solution B	5.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sodium Hydroxide	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ammonium Hydroxide	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other	4.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N-methylglucamine	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Copper Coating	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Copper Lacquer	0.0	0.0	0.0	53.6	0.0	0.0	0.0	53.6	53.6
Copper Powder	0.0	0.0	0.0	0.0	10.5	0.0	0.0	10.5	10.5
Base Coat Paint	0.0	0.0	0.0	0.0	0.0	56.2	0.0	0.0	0.0
Top Coat Paint	0.0	0.0	0.0	0.0	0.0	0.0	55.8	0.0	0.0
Silver	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.4
Recycle Water	0.0	0.0	4747.5	0.0	0.0	0.0	0.0	0.0	0.0

Stream Number	**64**	**65**	**66**	**67**	**68**	**69**	**70**	**71**
Temperature (°C)	36.9	25.0	25.0	143.3	25.0	25.0	143.3	25.0
Pressure (psi)	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7
Vapor Fraction	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mass Flow (g/min)	5684.6	5684.6	5740.8	5740.8	5740.8	5796.6	5796.6	5796.6
Component Mass Flow								
Glass	5637.5	5637.5	5637.5	5637.5	5637.5	5637.5	5637.5	5637.5
Distilled Water	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cerium Oxide	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sensitizer	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Propyl Alcohol	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hydrochloric Acid	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Stannous Chloride	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Water	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Peacock Silver A	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Silver Diammine	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ammonium Hydroxide	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Water	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Peacock Solution B	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sodium Hydroxide	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ammonium Hydroxide	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N-methylglucamine	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Copper Coating	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Copper Lacquer	53.6	53.6	53.6	53.6	53.6	53.6	53.6	53.6
Copper Powder	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5
Base Coat Paint	0.0	0.0	56.2	56.2	56.2	56.2	56.2	56.2
Top Coat Paint	0.0	0.0	0.0	0.0	0.0	55.8	55.8	55.8
Silver	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Recycle Water	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

2.5 Equipment Tables

Table 2.2. Mixers for glass silvering process.

Equipment	Water Mixer	Slurry Mixer	Sensitizer + Water Mixer	Silver A + B + Water Mixer	Reducer + Water Mixer	Copper Lacquer + Powder Mixer
ID	M-101	M-201	M-202	M-203	M-204	M-205
Material	Stainless Steel	Stainless Steel	Stainless Steel	Stainless Steel	Stainless Steel	Stainless Steel
Volume (L)	3740.77	126.01	218.93	83.99	84.02	28.49
Temperature (°C)	25.00	25.00	25.00	25.00	25.00	25.00
Pressure (psi)	14.70	14.70	14.70	14.70	14.70	14.70
Power (W)	1105.36	248.23	64.69	82.72	165.52	0.00
Time Handle (hr)	8.00	8.00	8.00	8.00	8.00	8.00
Flow Rate In (kg/hr)						
DI Water	0.00	12.60	26.32	9.80	10.50	0.00
Waste Water	467.60	0.00	0.00	0.00	0.00	0.00
Cerium Oxide	0.00	5.67	0.00	0.00	0.00	0.00
Sensitizer	0.00	0.00	1.09	0.00	0.00	0.00
Silver A	0.00	0.00	0.00	0.41	0.00	0.00
Silver B	0.00	0.00	0.00	0.39	0.00	0.00
N - methylglucamine	0.00	0.00	0.00	0.00	0.01	0.00
Copper Powder	0.00	0.00	0.00	0.00	0.00	0.63
Copper Lacquer	0.00	0.00	0.00	0.00	0.00	3.22
Backing Paint	0.00	0.00	0.00	0.00	0.00	0.00
Flow Rate Out (kg/h)						
DI Water	467.60	12.60	26.32	0.00	10.50	0.00
Waste Water	0.00	0.00	0.00	0.00	0.00	0.00
Cerium Oxide	0.00	5.67	0.00	0.00	0.00	0.00
Sensitizer	0.00	0.00	1.09	0.00	0.00	0.00
Silver A	0.00	0.00	0.00	0.00	0.00	0.00
Silver B	0.00	0.00	0.00	0.00	0.00	0.00
Silver Mixture	0.00	0.00	0.00	10.61	0.00	0.00
N - methylglucamine	0.00	0.00	0.00	0.00	0.01	0.00
Copper Powder	0.00	0.00	0.00	0.00	0.00	0.63
Copper Lacquer	0.00	0.00	0.00	0.00	0.00	3.22
Backing Paint	0.00	0.00	0.00	0.00	0.00	0.00

Table 2.3a. Storage vessels for glass silvering process.

Equipment	Water Storage Tank	Polish Holding Tank	Sensitizer Holding Tank	Silver A Holding Tank
ID	TK-101	TK-201	TK-202	TK-203
Material	Plexiglas	Carbon Steel	Plexiglas	Plexiglas
Volume (L)	7481.55	2268.20	753.35	249.60
Temperature (°C)	25.00	25.00	25.00	25.00
Pressure (psi)	14.70	14.70	14.70	14.70
Time Handle (hr)	16.00	720.00	720.00	720.00
Flow Rate In (kg/hr)				
DI Water	467.60	0.00	0.00	0.00
Waste Water	0.00	0.00	0.00	0.00
Cerium Oxide	0.00	5.67	0.00	0.00
Sensitizer	0.00	0.00	1.09	0.00
Silver A	0.00	0.00	0.00	0.41
Silver B	0.00	0.00	0.00	0.00
N - methylglucamine	0.00	0.00	0.00	0.00
Copper Powder	0.00	0.00	0.00	0.00
Copper Lacquer	0.00	0.00	0.00	0.00
Backing Paint	0.00	0.00	0.00	0.00
Flow Rate Out (kg/hr)				
DI Water	467.60	0.00	0.00	0.00
Waste Water	0.00	0.00	0.00	0.00
Cerium Oxide	0.00	5.67	0.00	0.00
Sensitizer	0.00	0.00	1.09	0.00
Silver A	0.00	0.00	0.00	0.41
Silver B	0.00	0.00	0.00	0.00
Silver Mixture	0.00	0.00	0.00	0.00
N - methylglucamine	0.00	0.00	0.00	0.00
Copper Powder	0.00	0.00	0.00	0.00
Copper Lacquer	0.00	0.00	0.00	0.00
Backing Paint	0.00	0.00	0.00	0.00

Table 2.3b. Storage vessels continued from above.

Equipment	Silver B Holding Tank	Reducer Holding Tank	Copper Lacquer Holding Tank	Copper Powder Holding Tank
ID	TK-204	TK-205	TK-206	TK-207
Material	Plexiglas	Carbon Steel	Plexiglas	Carbon Steel
Volume (L)	249.58	4.72	2514.00	50.43
Temperature (°C)	25.00	25.00	25.00	25.00
Pressure (psi)	14.70	14.70	14.70	14.70
Time Handle (hr)	720.00	720.00	720.00	720.00
Flow Rate In (kg/hr)				
DI Water	0.00	0.00	0.00	0.00
Waste Water	0.00	0.00	0.00	0.00
Cerium Oxide	0.00	0.00	0.00	0.00
Sensitizer	0.00	0.00	0.00	0.00
Silver A	0.00	0.00	0.00	0.00
Silver B	0.39	0.00	0.00	0.00
N - methylglucamine	0.00	0.01	0.00	0.00
Copper Powder	0.00	0.00	0.00	0.63
Copper Lacquer	0.00	0.00	3.22	0.00
Backing Paint	0.00	0.00	0.00	0.00
Flow Rate Out (kg/hr)				
DI Water	0.00	0.00	0.00	0.00
Waste Water	0.00	0.00	0.00	0.00
Cerium Oxide	0.00	0.00	0.00	0.00
Sensitizer	0.00	0.00	0.00	0.00
Silver A	0.00	0.00	0.00	0.00
Silver B	0.39	0.00	0.00	0.00
Silver Mixture	0.00	0.00	0.00	0.00
N - methylglucamine	0.00	0.01	0.00	0.00
Copper Powder	0.00	0.00	0.00	0.63
Copper Lacquer	0.00	0.00	3.22	0.00
Backing Paint	0.00	0.00	0.00	0.00

Table 2.4. Pumps for glass silvering process.

Equipment	Water Pump	Sensitizer Pump	Silver A Pump	Silver B Pump	Recycle Water Pump	Copper Lacquer Pump
ID	P-101 A/B	P-201 A/B	P-202 A/B	P-203 A/B	P-204 A/B	P-205 A/B
Type	Centrifugal	Centrifugal	Centrifugal	Centrifugal	Centrifugal	Screw
Material	Stainless Steel	Stainless Steel	Stainless Steel	Stainless Steel	Stainless Steel	Stainless Steel
Efficiency	45%	45%	45%	45%	45%	45%
Temperature (°C)	25.00	25.00	25.00	25.00	25.00	25.00
Pressure (psi)	60.00	40.00	40.00	40.00	55.00	40.00
Power (W)	324.60	0.41	0.13	0.13	179.54	1.35
Flow Rates (kg/hr)						
Water	467.60	0.00	0.00	0.00	216.79	0.00
Sensitizer	0.00	1.09	0.00	0.00	0.00	0.00
Silver A	0.00	0.00	0.41	0.00	0.00	0.00
Silver B	0.00	0.00	0.00	0.39	0.00	0.00
Lacquer	0.00	0.00	0.00	0.00	0.00	3.22
Backing Paint	0.00	0.00	0.00	0.00	0.00	0.00

Table 2.5a. Specialty equipment for glass silvering process.

Equipment	RO System	DI System	Edge Grinder/ Polisher	Optical Analyzer	Humidifiers (10)	Hoist Glass Storage
ID	R-101	R-101	G-101	A-101	N/A	N/A
Material	N/A	N/A	N/A	N/A	N/A	N/A
Power (kW)	1.00	1.00	19.50	10.00	1.35	25.00
Temperature (°C)	25.00	25.00	25.00	25.00	25.00	25.00
Pressure (psi)	95.00	55.00	14.70	14.70	14.70	14.70
Flow Rate (kg/hr)						
Water	467.60	467.60	0.00	0.00	20.74	0.00
Solid Waste	0.00	0.00	0.00	0.00	0.00	0.00
Sensitizer	0.00	0.00	0.00	0.00	0.00	0.00
Silver Waste	0.00	0.00	0.00	0.00	0.00	0.00

Table 2.5b. Specialty equipment continued from above.

Equipment	Water Heaters - First Stage	Water Heater - Second Stage	Centrifuge	Air Exhaust Filter 1	Air Exhaust Filter 2
ID	N/A	N/A	R-201	F-101 A/B	F-102 A/B
Material	Stainless Steel	Stainless Steel	Stainless Steel	N/A	N/A
Power (kW)	3.50	3.50	0.00	0.00	0.00
Temperature (°C)	50.00	50.00	25.00	25.00	25.00
Pressure (psi)	40.00	40.00	14.70	14.70	14.70
Flow Rate (kg/hr)					
Water	68.06	68.06	80.66	5.26	0.00
Solid Waste	0.00	0.00	5.67	0.00	0.00
Sensitizer	0.00	0.00	0.00	0.22	0.00
Silver Waste	0.00	0.00	0.00	0.00	2.12

Table 2.6a. Conveyer belts/rollers for glass silvering process.

Equipment	Rinsing Conveyer	Cooling Conveyer	Glass Conveyer 1	Glass Conveyer 2	Glass Conveyer 3
ID	C-101	C-102	C-203	C-204	C-205
Type	Roller	Roller	Roller	Roller	Roller
Power (W)	1.95	9.75	0.78	0.78	0.78
Length (m)	5.00	25.00	2.00	2.00	2.00
Width (m)	1.80	1.80	1.80	1.80	1.80
Belt Speed (m/min)	5.00	1.00	5.00	5.00	5.00
Flow Rate (kg/hr)					
Glass/Mirror	338.25	338.25	338.25	338.25	338.25
Sensitizer	0.00	0.00	0.00	0.00	0.00
Silver	0.00	0.00	0.00	0.00	0.00
Copper Paint	0.00	0.00	0.00	0.00	0.00
Backing Paint	0.00	0.00	0.00	0.00	0.00

Table 2.6b. Conveyer belts/rollers continued from above.

Equipment	Glass Conveyer 4	Cooling Tunnel Conveyer 1	Cooling Tunnel Conveyer 2	Cooling Tunnel Conveyer 3
ID	C-206	C-208	C-209	C-210
Type	Roller	Roller	Roller	Roller
Power (W)	0.78	5.90	5.97	6.03
Length (m)	2.00	15.00	15.00	15.00
Width (m)	1.80	1.80	1.80	1.80
Belt Speed (m/min)	5.00	5.00	5.00	5.00
Flow Rate (kg/hr)				
Glass/Mirror	338.25	338.25	338.25	338.25
Sensitizer	0.00	0.00	0.00	0.00
Silver	0.02	0.02	0.02	0.02
Copper Paint	0.00	3.85	3.85	3.85
Backing Paint	0.00	0.00	4.51	8.98

Table 2.7. Screw conveyers for glass silvering process.

Equipment	Polish Screw Conveyer	Reducer Screw Conveyer	Powder Screw Conveyer
ID	C-201	C-202	C-207
Type	Screw Conveyer	Screw Conveyer	Screw Conveyer
Power (W)	0.58	0.00	0.09
Length (m)	2.00	2.00	2.00
Diameter (m)	0.15	0.15	0.15
Flow Rate (kg/hr)			
Cerium Oxide	5.67	0.00	0.00
N - methylglucamine	0.00	0.01	0.00
Copper	0.00	0.00	0.63

Table 2.8. Furnaces and dryers for glass silvering process.

Equipment	Slump/ Annealing Furnace	Silver Dryer	Copper Dry Oven	Base Coat Baking Oven	Top Coat Baking Oven
ID	H-101	H-201	H-202	H-203	H-204
Type	Heater	Heater	Heater	Heater	Heater
Temperature (°C)	1200.00	25.00	150.00	417.00	417.00
Power (kW)	540.00	24.00	80.00	80.00	80.00
Flow Rates (kg/hr)					
Glass	338.25	338.25	338.25	338.25	338.25
Silver	0.00	0.02	0.02	0.02	0.02
Copper Paint	0.00	0.00	3.85	3.85	3.85
Backing Paint	0.00	0.00	0.00	4.51	4.47

Table 2.9a. Sprayers for glass silvering process.

Equipment	Rinse Spray	Rinse Spray	Polish Scrubber	Rinse Spray
ID	S-101	S-201	S-202	S-203
Type	Cone Spray	Cone Spray	Drip	Cone Spray
Material	Aluminum	Aluminum	N/A	Aluminum
Temperature (°C)	25.00	25.00	25.00	50.00
Power (kW)	10.00	10.00	28.00	10.00
Belt Speed (m/min)	5.00	5.00	5.00	5.00
Length (m)	5.00	5.00	7.80	5.00
Flow Rate (kg/hr)				
Water	68.06	68.06	12.60	68.06
Cerium Oxide	0.00	0.00	5.67	0.00
Sensitizer	0.00	0.00	0.00	0.00
Silver Solution	0.00	0.00	0.00	0.00
N - methylglucamine	0.00	0.00	0.00	0.00
Glass	338.25	338.25	338.25	338.25

Table 2.9b. Sprayers continued from above.

Equipment	Sensitizer Station	Rinse Spray	Silver Station	Rinse Spray
ID	S-204	S-205	S-206	S-207
Type	Flat Spray	Cone Spray	Dual Flat Spray	Cone Spray
Material	Stainless Steel	Aluminum	Stainless Steel	Aluminum
Temperature (°C)	25.00	50.00	25.00	25.00
Power (kW)	15.00	10.00	15.00	10.00
Belt Speed (m/min)	5.00	5.00	5.00	5.00
Length (m)	5.00	5.00	5.00	5.00
Flow Rate (kg/hr)				
Water	26.32	68.06	10.50	68.06
Cerium Oxide	0.00	0.00	0.00	0.00
Sensitizer	1.09	0.00	0.00	0.00
Silver Solution	0.00	0.00	10.61	0.00
N - methylglucamine	0.00	0.00	0.01	0.00
Glass	338.25	338.25	338.25	338.27

Table 2.10. Curtain coaters for glass silvering process.

Equipment	Copper Paint Curtain Coater	Base Coat Curtain Coater	Top Coat Curtain Coater
ID	CC-201	CC-202	CC-203
Type	Curtain Coater	Curtain Coater	Curtain Coater
Power (kW)	10.00	10.00	10.00
Length (m)	6.00	6.00	6.00
Flow Rate (kg/hr)			
Glass	338.25	338.25	338.25
Copper Lacquer	3.85	0.00	0.00
Backing Paint	0.00	4.51	4.47

Table 2.11a. Throttling valves for glass silvering process.

Equipment	Rinse Valve	Rinse Valve	Polish Mixer Valve	Polish Machine Rinse	Rinse Valve
ID	V-101	V-102	V-103	V-104	V-105
Type	Throttling	Throttling	Throttling	Throttling	Throttling
Inlet Pressure (psi)	60	60	60	60	60
Outlet Pressure (psi)	40	40	40	40	40
Flow Rate (kg/hr)					
Water	68.06	68.06	12.06	68.06	68.06

Table 2.11b. Throttling valves continued from above.

Equipment	Sensitizer Mixer Valve	Rinse Valve	Silver Mixer Valve	Reducer Mixer Valve	Rinse Valve
ID	V-106	V-107	V-108	V-109	V-110
Type	Throttling	Throttling	Throttling	Throttling	Throttling
Inlet Pressure (psi)	60	60	60	60	60
Outlet Pressure (psi)	40	40	40	40	40
Flow Rate (kg/hr)					
Water	26.32	68.06	9.80	10.50	68.06

2.6 Utility Tables

Table 2.12. Utility use for glass silvering process.

Electricity	
Rate USD/kWh	$0.07
Energy kWh/day	8072.45
Annual Cost	$109,000.00
Humidifier Water	
Rate USD/1000 liter	$0.77
Flow Rate L/day	166.03
Annual Cost	$27.00
Nitrogen	
Rate USD/kg	$0.034
Flow Rate kg/day	3529.41
Annual Cost	$31,000.00
Landfill	
Rate USD/1000 kg	$17.38
Flow Rate kg/day	45.364
Annual Cost	$165.00
Total Annual Cost	**$140,000.00**

2.7 Written Description of Process

2.7.1 Detailed Description

The full process flow diagram is presented in Figures 2.2a-c. The diagram contains three main components – the glass line, the water flow line, and the input chemical lines. Tap water purchased from a local water company in Stream 1 is mixed in M-101 with recycled process water. The water mixture is then sent through a reverse osmosis and deionization system, R-101, to generate 99.9% purified water (Dual Bed Deionization Systems n.d.). This high purity is critical to ensure good bonding between applied layers (Czanderna 8). The purified water is sent to a storage tank, TK-101, and used as necessary during plant operation. The valves, V-101 through V-110, control the flow from this tank to ten different water lines, which provide water to different sections of the plant.

The flat float glass, precut to the desired dimensions, enters the process in Steam 3. The glass is immediately rinsed with water to wash off any particulates that may have settled on the sheets during shipment. This is important so that particulates do not scratch the glass in subsequent processes. In Streams 9 and 10, the sheets run on a conveyer belt, C-101, through the edge grinder and polisher, G-101. This prevents breakage by eliminating sharp edges on the panel, which concentrate stress points on the glass (Mirrors: Handle with Extreme Care 6). At this point, the glass is ready to be slumped into its disk shape. Using a mechanical arm, operators take these pieces and carefully place them on one of the three slump molds in H-101. The molds protrude upwards at each of the four corners as is shown in Figure 2.3 below, so the glass is only supported at those points, which requires a high degree of precision when positioning the glass. The mechanical arm shields the operators from the high temperatures of the furnace. Once all the glass pieces are mounted, the glass quickly heats up from room temperature to 710°C, at which point it sags into the desired shape. The furnace is then programmed to begin cooling the glass to the lower end of its transitional temperature range, 550°C. Here, the shape becomes relatively stable. Afterwards, the furnace begins a slower cooling cycle in order to anneal the glass and fully stabilize its shape. This entire process, described later in detail, takes 12 minutes to perform. This makes it necessary to slump three pieces at the same time, as shown in H-101, to meet production requirements. The glass is removed from the furnace in Stream 11 at a temperature of 500°C. It then journeys down a long, slow moving conveyor, C-102, where, over a period of 25 minutes, the glass cools to room temperature. It is important at this point to perform analytical tests on the glass to ensure that the slumping process worked as intended. A laser profiler, A-101, is used to analyze the surface and confirm that the slumped glass meets the specifications. Preferably, this testing is only required for a few of the mirrors, for instance one in each furnace run.

Figure 2.3. Slump mold for flat glass panels.

The shaped glass is then stored in vertical glass storage racks for later use in the silvering process. The proposed design has a capacity of preparing 100 glass pieces every eight-hour workday. The second room of the plant, where the glass is coated, is not useful until 100 pieces are slumped and ready to go. Therefore, the first day of plant operation involves using only the first room and slumping the first 100 pieces to silver the next day. Each day afterwards, 100 glass pieces are slumped for use the next day, while the previous day's glass is mirrored in the second room.

In Process Room 2, the slumped glass from Room 1 undergoes a series of machines on a conveyor process. It is imperative that the glass is placed on the conveyor concave side up because this is a back silvering process. As in Room 1, the glass is first rinsed off, in S-201, to get rid of large particulates that may have settled during its time on the storage racks. Then, in Stream 21, the glass proceeds to the scrubber in S-202.

The scrubber polishes the glass surface with a cerium oxide (CeO_2) slurry. This abrasive essentially removes a couple nanometers from the glass surface and creates a very smooth finish, which is ideal for the subsequent chemical depositions. The slurry is prepared via Streams 14 and 23. In Stream 14, the cerium oxide enters a mixing tank, M-201 through a screw conveyor, C-201. It is then liquefied with water from Stream 23. The resulting slurry, Stream 24, is sent to the scrubbers, S-202. After the glass is scrubbed with slurry, the slurry is rinsed and brushed off, via the water from Stream 27.

At this point, after the wash, it is essential that the back surface of the glass remain wet at all times until the silver is deposited and dried. The glass leaving the slurry station, Stream 28, is rinsed again with water. The rinse water, Stream 31, is heated with an electric water heater to 50°C. When this water, Stream 32, comes in contact with the glass, it will heat up the glass to around 37.2°C, which allows for better adherence of chemicals (Hughes 2014). The glass then proceeds to the sensitizing station.

The sensitizer solution, prepared by mixing sensitizer in Stream 15 with dilution water in Stream 36, is a chemical containing tin chloride (or stannous chloride) and is used to deposit a layer of tin particles that is just nanometers thick on the surface of the glass. This tinning of the surface creates agglomeration points for the silver to adhere onto. After application, the sensitizer is immediately rinsed. This is done using heated water from Stream 42, similar to a step previously described. This thorough rinse will remove everything except the tin layer, which is bonded to the surface and cannot be rinsed away (Czanderna et al. 22). The heated water will also increase the temperature of the glass, allowing for improved silver adhesion in the spray station, S-206.

During the most significant step of the Room 2 process, silver is deposited onto the glass surface via a reduction oxidation reaction. This necessitates that the silver chemicals be prepared in such a way that one possesses a strong activation capability and another a reduction capability. Silver A, the main silver solution containing silver diammine, is pumped from its storage tank to a mixer in Stream 16. Silver B in Stream 17, an activator solution, is also similarly pumped to the mixer, M-203. Simultaneously water in Stream 46 is added to the mixture in order to dilute the chemicals and create the final activated silver solution, Stream 47.

On a separate mixing mechanism the reducing solution is prepared. The reducer used in this process is N-methylglucamine (meglumine). The meglumine enters mixer M-

204 from Stream 18 to be diluted with water from Stream 48. The resulting reducing solution is then fed out at Stream 49.

Since the silver is applied through sprayers in S-206, it is necessary to use dual nozzle sprays to simultaneously apply the activated silver and reducing solutions. When the two contact the surface of the glass, the reduction oxidation reaction immediately takes place and a layer of reflective silver begins to form. The sprays are designed so that a roughly 70 nm thick silver coating deposits on the surface. The silvered mirror is then transferred onto a conveyor to receive a final water rinse, and then dried using a convective air dryer, H-201.

The fully dried, silvered mirror, Stream 56, must then be protected by adding several layers of paint coatings. The first coating that is applied is a copper-based paint. This ensures that if contamination passes through the paint layer, the copper layer will corrode before the silver layer, preventing damage to the mirror (Products 2014). This metallic paint is developed using a lacquer solution and copper powder mixer and is a critical protection separating the silver from environmental degradation. The lacquer and powder enter the mixer, M-205, from Streams 58 and 59 respectively. The copper paint, Stream 62, then is inputted into the curtain coating machine, CC-201, which has a built in paint storage. In addition to holding the paint input, the paint storage also captures the excess paint flowing from the curtain and recycles it back through the system to prevent wastage. The mirrors, from Stream 56, enter the curtain coater straight from the dryer. Paint flows continuously in a smooth curtain from the paint dispenser via gravity and viscous forces. The curtain coater evenly and smoothly deposits 3 mils of copper paint onto the mirror.

The mirror is then sent to a drying oven, H-202, where the copper paint solvents flash off and the paint dries immediately due to high heat. The oven operates at a temperature of 150°C, which causes the glass to heat up. It therefore flows down a cooling tunnel conveyor and into the next paint station. The additional paint layers act as further kinetic barriers to the copper layer. First 3 mils of a base coat is applied, via another curtain coater, CC-202, operating similar to the one previously described. However, this paint is a thermal set paint and requires more heat treatment to cure the paint. After the base coat paint is applied, Stream 66, the glass must be heated to 290°F or 143.3°C. This requires the furnace to be at 437°C. Once the glass reaches that temperature, it takes the paint two to three minutes to cure. The coated mirror, Stream 67, then travels down another cooling tunnel conveyor, C-209, before applying the final topcoat paint layer. This process is analogous to the one just described for the base coat and the ultimate result is a fully silvered, coppered, and back painted glass mirror in Stream 71.

In addition to this main silvering line, the PFD in Figure 2.2a-c also shows handling of the waste streams in each station. The water running off from each of the early stage rinses - Stream 8, Stream 20, Stream 25 and Stream 33 – is collected into a recycle water drain and pumped back to the RO/DI system, Stream 57, to minimize water use. Specifically, Stream 25 contains a slurry – water mixture and must be treated with a centrifuge, R-201, first. This creates a fairly pure, solid cerium oxide, Stream 29, which is transported to a different industry for further treatment. The remaining water, Stream 26, joins the recycle stream.

Rinses after the sensitizing station are not allowed to recycle back because they have come in contact with hazardous chemicals and require more extensive mechanisms to treat. Thus, the runoff from the sensitizer station, Stream 38, and its following rinse, Stream 43, are combined in Stream 45 and released into the sewage system. There is also some overspray that occurs in the station, which is vented out in Stream 39, through a filter and into the atmosphere.

Runoffs from the silvering station and its subsequent rinse, Streams 52 and 54, are also treated in a similar manner and combine together in Stream 55. The overspray is vented out into the atmosphere in Stream 50. The liquid silver waste is very valuable because it still contains a lot of usable silver chemicals. The proposed process does not have the means to treat this silver waste on site, but it is transported to another company that will buy the waste and perform those services.

2.8 Rationale for Process Choice

Since the success of the CPV system, and in turn that of the reflector production plant, hinges on the ability to provide a financially and ecologically cost effective product, each step in the process described plays an important role in the overall marketability. During the silvering process, there are many aspects of the glass shaping and silvering that can differ based on choices to make the process cheaper, safer, more environmentally friendly. Three specific parts of the process that are optimized are the mechanisms used for glass shaping and glass strengthening, and the choice of chemicals used to apply the silver on the surface of the glass.

2.8.1 Location Rationale

One of the preliminary choices for the plant is its construction location in Tucson, Arizona. In addition to its proximity to the current REhnu headquarters, Tucson also lies in the desert southwest that is known for its consistent exposure to the sun. In fact, Tucson is amongst the top five cities in the United States in terms of average hours of sun per day (Solar Electric System 2014). Since sunlight is the most critical raw material for the final CPV system, Tucson provides an ideal location. The mirrors produced from this plant could potentially be used in a solar farm developed nearby, which greatly reduces transportation costs and the environmental impacts of transportation. Tucson is also attractive from an environmental view. The city enjoys one of the best air qualities in the country, ranking number 1 in cleanest metropolitan area in the country for 24-hour particle pollution (Tucson, AZ 2013). This is important because excess air contamination caused by pollution in urban areas is a significant cause of solar mirror degradation. Furthermore, Tucson is a dry location, so humidity will not play a factor in mirror degradation. The fact that Tucson is an inland city provides even more benefits. Many coastal cities, like those in California, have high salt concentrations in the air, which is detrimental to the mirrors (Czanderna et al. 50). From an economic point of view, Tucson is ranked as one of the best locations for the solar industry, already housing some large photovoltaic manufacturers and heavily funding research in the field in universities (Age of Alternative Energy 2010).

2.8.2 Production scale

To fully reap the benefits that Tucson has to offer as a plant location, the proposed production design must be highly optimized to meet its requirements. It should be noted that the plant’s production rate is not nearly as high as other companies that produce solar mirrors. The plant will make 26,000 mirrors annually, compared to the 1.3 million-mirror capability of RioGlass located just north in Surprise, Arizona. Additionally, the desired mirrors must be of very high quality, with a reflectivity of 95%. This generates even more tension for optimization in order to create a successful midscale plant.

With this in mind, a conveyor process is chosen to perform the mirroring. In general, silvering quantities up to 200 square meters a day is best performed by hand. However, the current facility silvers 272 square meters a day, making the conveyor process the more appropriate (Schweig 166). The fact that the production is so close to this threshold suggests that the installed conveyor process can accommodate faster production. Although it is not necessary to account for this with the current proposal, it is desirable to create optimizations that perform well now and also allow for scale up in the future.

2.8.3 Glass Shaping

Several different methods are possible for molding the glass into the unique paraboloidal shapes necessary for the solar concentrators. The methods that can be used are a slump mold, gravity molding, or mechanical bending of the glass. In slump molding, a mold is created that the glass can depress into or around. This allows the exact shape be formed with high fidelity, but causes optical defects in the glass. The mold is often slightly patterned or has pressure points that can cool parts of the glass as it hits the mold. For this reason, there are small defects in the glass that may lead to a decrease in reflectivity or precision (Yoshizawa 1). The design evaluated is a mold that is concave, allowing the glass to slump inward. This keeps any surface defects on the convex side of the paraboloid, which is the side that will be silvered as opposed to the concave, reflecting surface to minimize impacts. Using such a mold makes it difficult to temper the glass, discussed in Section 2.8.4, because one side of the glass is in contact with a solid surface after shaping.

The second form of glass shaping evaluated is gravity shaping of glass, which was invented due to a demand for curved windshields. In gravity shaping, the glass is suspended using a fluid and heated to between 650˚C and 750˚C, which is the transition temperature range at which glass readily deforms. Once it reaches the deformation temperature, pressure is applied around the edges of the glass to support it as the center curves downward due to the force of gravity. This method leaves very little surface deformation and allows for tempering to be done in a single step. However, for paraboloidal mirrors, it is difficult to obtain the necessary precision to create the paraboloid with the exact focal point needed to concentrate the energy (McMaster et al., "Method and Apparatus" 1-3).

Mechanical bending is the method of formation currently used by RioGlass in forming their trough shaped mirrors (RioGlass 2013). When a sheet of glass, is mechanically bended, it is heated in a furnace to the transition temperature of glass, then is run through a set of rollers that curves the glass. This method also lends itself to immediate tempering, because air streams can be added to the line to quench the surface temperature directly after the glass is bent. This method of shaping can also lead to surface deformation. Though this method is very practical for trough shaped mirrors, there are currently no roller systems designed to form paraboloids, which requires shaping in two directions. Further evaluation and design could be done to design a spherical rolling system to produce paraboloidal mirrors (McMaster et al., "Glass Bending" 2-4).

Upon evaluating the three common methods, the ideal method for producing paraboloidal mirrors is using a concave slump mold. This will isolate the defects to the silvered, non-reflecting side of the glass and allow for high precision in producing the mirrors with an ideal focal point. This design implicates that annealing is a better option than tempering the glass.

2.8.4 Glass Strengthening

Once the glass is shaped, it must be strengthened before it can be silvered. For the silvering process, both annealed and tempered glass may be used. Tempering glass provides several advantages for the silvering process and increases the lifetime of the mirrors. Tempering is achieved by rapidly cooling the glass surface while maintaining a high internal temperature. As the center cools, this creates a large amount of internal stress, which strengthens the glass. Glass that has been tempered is less susceptible to breaking, which allows the glass to be handled less gently during the silvering process while on the conveyer belts. It also gives it a distinct advantage when exposed to harsh weather such as hail. Further, should a piece of glass break during the silvering process, tempered glass will shatter into small pieces that will fall through the conveyers. This allows the broken glass to be disposed of while production continues. Annealed glass will break into large shards, requiring production to stop in order for the broken glass to be cleared (Barr 1).

Both tempering and annealing are done while cooling glass. Glass is tempered by rapid cooling the surface of the glass while it retains a high internal temperature. This is normally done by exposing both sides of the glass to cool air streams that cause rapid convective heat transfer. The temperature gradient in the glass creates a stress that strengthens the glass upon cooling (Barr 1). If the stress is uneven, however, it can deform the glass. As the focal point of the paraboloidal mirrors is the most important feature of the mirrors, deforming the glass could change the focal point, risking the entire mirror.

To anneal glass, the piece of molded glass is brought to around 500^{o}C, just below the transition point of glass, which is slightly different for different types and thicknesses of glass. Holding the external surfaces of the glass at the same temperature as the inner layer of the glass reduces stresses that occur during the cooling process. Reducing the stresses caused by temperature gradients ensures the glass retains its shape as it cools. However, the lack of internal stress reduces the strength of the glass and makes it more likely to break when dropped, struck, or if pressure is in some way applied (Hann 1).

Tempering is currently performed in industry by RioGlass, which produces only parabolic, trough shaped mirrors (RioGlass 2013). Because of the shape of the mirrors, they are able to cool the bent glass with one continuous air stream that will simultaneously cool both sides of the shaped glass. This reduces the risk of glass deformation by eliminating potential variations in the flow rate or temperature of the cooling air stream (Coughenour 2014). However, with paraboloidal shaped mirrors, two air streams must be used to cool the glass, one for the convex and one for the concave sides of the mirrors. This introduces significantly more error into the tempering process due to fluctuations in the temperature gradients discussed earlier. The cost of the equipment to be able to perform this with high precision is also too high for current consideration. Thus, even though tempering is in principle a better strengthening method, annealing is by far more preferable for the current process.

2.8.5 Reducer Selection

For silvering, a reducing solution is applied with the silver in order to reduce the silver diammine to release the silver cation that is applied to the glass. For the process, based on laboratory testing, chemicals from Peacock Labs, Inc. are used for sensitizing, silvering, and coppering. For the reducing solution, the Peacock Labs reducer was evaluated as well as N-methlyglucamine reducers.

The HE-300C Reducer from Peacock Labs is the reducing solution typically sold with the Peacock silvering solutions. The reducer from Peacock contains dextrose as a reducing agent as well as formaldehyde as a non-active ingredient (MSDS HE-300C 2000). In the original silvering procedure proposed and practiced by REhnu, the HE-300C reducer was used. During these trials, the reflectivity of the mirrors was too low, at only 75% where the target is 95% for solar mirrors (Olbert, "Reflector Processing" 5).

Due to the low reflectivity obtained using the Peacock reducer and the large safety and environmental hazards associated with the formaldehyde in HE-300C, other reducers were evaluated. In a 1988 patent, Harry Bahls proposed several different formulations of reducing solutions using N-methylgucamine, D-glucamine, or glucosaminic acid. The reducers proposed by Bahls contain both sodium hydroxide and ammonium hydroxide, which lowers the pH and accelerates the reaction between the reducing agent and the silver diammine (Bahls 5). The addition of base to improve the performance reducing agent is consistent with research performed by other research groups. Chou et al. discovered that adding increasing concentrations of alkaline ions to the reducer, which in their case was dextrose, increases the conversion of the silver ion (430). However, REhnu did testing with a reducer containing only water and N-methylglucamine and the procedure yielded the high reflectivity desired (Olbert "Reflector Processing" 5). Due to the better safety considerations and the higher reflectivity obtained by using the N-methylglucamine reducer, only N-methylglucamine is used in the process.

2.8.6 Copper Backing Rationale

In order to protect the silver from degrading, several protective coatings must be added to the glass. The first layer of protection is a copper layer, which is then followed by a layer of paint or shellac. There are several methods that may be used for applying the copper to the back of the mirror. The first is galvanic or electrolytic deposition, developed by Justus Baron von Liebig. This method, which was popular until the 1950s, involves immersing the silvered glass in a solution opposite a copper plate. Current is run through the system, which allows the copper to be plated on the glass (Schweig 53).

This method, however, has nearly been entirely discontinued due to the equally effective, but much cheaper, electroless deposition mechanisms. A copper layer can be applied via spraying using a technique similar to that used for the reduction oxidation in the silvering. In this process, zinc or iron is added to liquid copper. The copper is applied as a spray and the added metal reduces the copper to deposit a copper layer over the silver layer. Sulfuric acid is often added to this process in order to speed up the reaction by decreasing the pH. This copper layer is generally two to three times thinner than the silver layer. This layer deposits a very even coat of copper with few defects that increases the lifetime of the silver, and therefore, the mirror (Czanderna et al. 26).

Another electroless method for depositing copper involves a copper paint backing. A paint backing exists from Peacock Labs as a two-part system consisting of Copper-Tite lacquer and copper powder. Copper powder is mixed into the lacquer, a clear paint coating, and they are applied together to the glass. The lacquer is formulated to create a strong bond between itself and the silver and can be applied alone as a protective finish. By adding the copper powder, a strong copper containing polymer coat is formed, which is intended to corrode in place of the silver should contaminants get through the paint backing (Peacock Labs 2013). This method less expensive, and the waste from the paint is easier to contain and reuse than with the spray method. Being able to contain the waste improves both the safety and environmental impacts of the process. That combined with the ease of application makes the lacquer-powder system preferable for the process.

2.8.7 Paint Backing Rationale

Backing paints are used in industrial solar mirrors to decrease the wear a mirror will experience while exposed to the elements. These backing paints must stand up to dust, rain, hail, snow, intense heat, intense cold, and any other types of weather that the mirror will experience during its lifetime. In order to best protect the mirrors, a heat-cured backing paint is preferable to a standard paint for the increased wear protection it provides, which is why it is used in this process (Schweig 69). A heat cure paint will dry in a prescribed time, here two to three minutes, within the limits of a minimum and maximum temperature. The particular paint used here, manufactured by PrimeNa Technologies, becomes tough and insoluble upon heating. By using a thermosetting paint, a more even coating is formed on the backing of the mirror in contrast to normal curing paints. This is due to the fact that the curing process occurs rapidly and simultaneously across the painting surface as well as through the paint backing thickness (Nike Tech Solar Top Coat 2012). In contrast, regular curing paints take a much longer time to cure and will cure at an uneven rate, resulting in a poorer finish on the mirror. The finish defects will decrease the lifespan of the paint backing and therefore will decrease the effective lifetime of the mirror itself. During production, the use of heat curing also speeds up the drying process of the paint significantly, allowing the mirrors to move through the line quicker and receive the second backing coat in a relatively short period of time. This increase in production rate and lifespan of the mirror help to offset the cost difference between the more expensive heat-cured paints and other spray coatings.

With respect to powder coatings, the real benefit of heat curing is seen in the cost throughout the painting process. While powder coatings do provide a better backing finish overall, the process for powder coating paints takes a considerably longer amount of time to finish as opposed to curtain coating. Likewise, the equipment and area needed for powder coating far exceeds the relatively simple curtain coating equipment (Iwasa et al. 1-2). Since both backings require heat curing, there is little difference in that aspect of the design. One of the larger reasons behind choosing the powder coating over the heat-cured paints is the elimination of volatile organic compounds released by the paints during the drying phase. Since the powder is, as the name implies, a dry powder, no volatile organic compounds (VOCs) are released during the painting and drying process, making this option more environmentally friendly. Because of this, powder-coating processes may be looked into as a future replacement to the current process.

3 Equipment Description, Rationale, Optimization

For all equipment sizing and power calculations, refer to Appendix C.

3.1 Storage Vessels

Most chemicals used in the plant will be purchased in bulk from supplies, which requires an effective way to store large amount of chemicals. Using an estimate of needing to house a 3-month supply, these containers will range from 5 to 7500 liters, as seen in Section 2.4. The only exception is the distilled water tank, which will only have the capacity to hold two days worth of water. This was done because of the size of the tank. All vessels will all be closed top storage tanks, which comes from the necessity to keep the chemicals pure and separated from any possible contamination. Any contamination would result in a poor quality product, justifying the measure. This is accomplished by using cone roof tanks. These tanks will include vents, which will allow the tanks to withstand any pressure changes that may be seen throughout the year due to weather and climate changes the may occur in Arizona. Based on the chemicals stored in the tank, different materials of construction are needed. For almost all liquid chemical storage, fiberglass vessels are preferred due to the chemical resistivity and low reactivity of the vessel. For the solid chemicals, including the polishing agent, N-methylglucamine, and copper powder, carbon steel vessels can be used for pricing reasons.

3.2 Conveyer Belts

Conveyer belts will be used throughout the process to moves the glass along the line until a finished mirror is produced. For almost every piece of equipment in the process, a conveyer belt is a built into the actual piece of equipment. The need for stand-alone conveyers is used exclusively for moving the glass to and from these different pieces of equipment. The largest conveyer needed will be for the final cooling process of the freshly slumped mirror (C-102). Due to the long cooling times, the conveyer runs for approximately 25 minutes. To account for this, the conveyer moves at a speed of one meter per minute, for a total distance of 25 meters. Conveyer belts after the paint curing ovens must also be longer to accommodate the cooling of the mirrors out of the oven (C-208 through C-210). These conveyers are much shorter, only 15 meters long, and run at a speed of five meters per minute. For all other conveyer belts, the only necessity will be to get the glass from one piece of equipment to the other in an automated process with a reasonable pace and distance. This is chosen to go at a speed of five meters per minute for a length of five meters, which is approximately the average length of the large pieces of equipment. This speed is chosen to produce one mirror every five minutes, which allows for the desired production rate of 100 mirrors per day. For all conveyer belts, a width of 1.8 meters is necessary to account for the size of the mirror. For belt materials, rubber rollers are used in order to reduce stress points on the glass and prevent possible scratching. Power requirements can be seen in Section 2.4.

3.3 Furnaces and Dryers

Due to the size and scope of the mirrors being produced in this design, a custom furnace needs to be made for the shaping process. In order to slump the glass to the required shape, they must remain in the furnace at 1200°C for approximately 50 seconds before being cooled to retain the paraboloidal shape. The rapid radiation heating allows the glass to heat up from room temperature. Still inside the furnace, the glass undergoes an annealing process at 500°C which lasts roughly two minutes. Following this annealing, the glass is moved out of the furnace. Each furnace is built to handle three glass pieces at time, so only one furnace is needed for the production rate of 100 mirrors per day. Specifications on the power calculations can be found in Table 2.8. The slumping furnace for this plant design is based off of a custom furnace used by the University of Arizona Mirror Lab, with calculations found in Appendix C.

Multiple smaller furnaces are also needed throughout the process in order to speed up the process and set the final backing paint layers. The first dryer (H-201) is needed after silvering has been completed to insure that all extra chemicals have been removed before the backing paints are applied. While heat is not necessary in this step, the dryer will blow air across the surface of the mirror in order to remove and aqueous layer still present on the silver surface. This dryer will need to be run at 25°C, with a total power usage of 24 kW. After each paint cycle (copper, base coat and top coat backing), the mirror will go through a dryer to speed up the drying process. For the copper lacquer, the dryer will operate at 150°C to establish a firm coating of copper to the silver. For both paint backings, a temperature of 280 to 290°C will need to be reached for roughly two and half minutes in order for the paint to set. This is due to the paints being heat cured, as discussed in Section 2.8.7. All three of these dryers require a power input of 80 kW, as seen in Table 2.8.

3.4 Pumps

Pumps will be used during the production of mirrors to move large amounts of liquid chemicals from storage to processing. The majority of the pumps used in this process are centrifugal pumps. This type of pump was chosen due to the reactivity and viscosity of chemicals that are being pumped, as well as the flow rates needed for production. Centrifugal pumps are used for all water, sensitizer, silver A, silver B, and reducer solutions pumped through the system. The only exception is the pump used for the copper paint (P-206). Due to the high viscosity of these chemicals, screw pumps will be used due to the lower strain on the pump.

To size the pumps in the plant, flow rates were made so that the entire days' supply of chemicals could be pumped to the mixer or sprayer within one hour. This gave a range of 0.5 to 62.5 liters per minute for all of the pumps. All flow calculations can be found in Appendix C. For the material of construction, stainless steel will be used to prevent corrosion and reactions between the chemicals being pumped and the pump itself.

3.5 Sprayers

Sprayers are one of the more crucial pieces of equipment in this plant design due to the overall amount of sprayers needed. Different types of sprayers will be used based on the types of chemicals that will be sprayed, as well as how much spray is needed in the process. For each spray set up, a line of seven sprayers in a line will be used so that there is sufficient overlap of spray on the mirrors, as well as four rows of sprayers to form a sufficient layer of the chemicals being sprayed, as seen in Figure 3.1 and Figure 3.2. These numbers are based off of a spray angle of 65°, resulting in a total spray of 23" per sprayer. With a complete overlap of each sprayer to get an even coating, seven sprayers will be needed to cover the 65" width of the mirror. All sprayers and their specifications are taken from Spraying Systems Co (A2). The sprayers themselves will be part of a larger piece of equipment that houses the sprayers and an internal conveyer belt. For the silvering and sensitizing sprayer systems, venting fans are also a part of the system to vent any vapor overspray. These vents also include chemical filter in order to capture any hazardous chemicals that would be sent into the atmosphere with the vent exhaust.

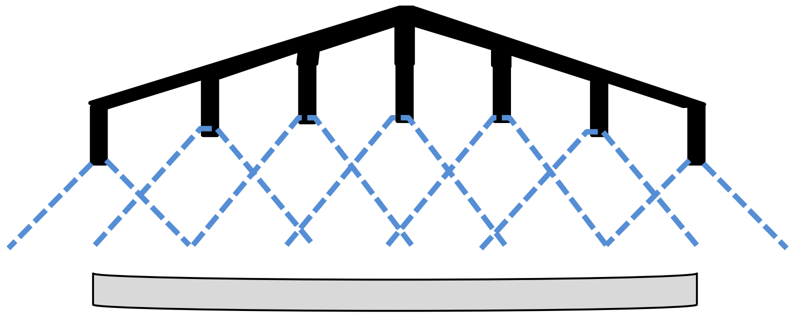

Figure 3.1. Sprayer assembly. Sprayers are set up so that there is complete overlap of spray over the entire length of the mirror.

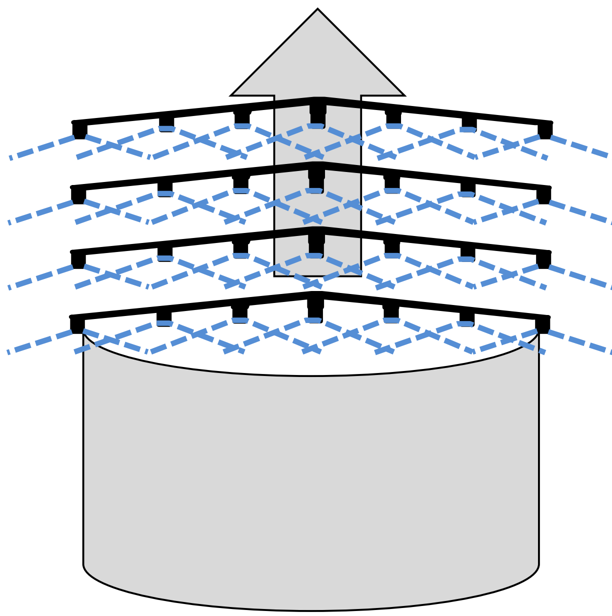

Figure 3.2. 7 Sprayer assembly in row. Mirrors travel down the line so that they pass under the four sprayers, ensuring an even coating across the mirror.

Water rinse sprays make up most of the sprayers in the system due to the necessity for the glass to be clean and stay wet throughout the process. These include Sprayers 101, 201, 203, 205, and 207. As described in Section 2.7.1, a failure to keep the glass wet in between sensitizing and silvering will lead to a poorly silvered product which would be unfit for sale. To account for this, the types of sprayers used for the water rinse cycles are automated full cone nozzles to spray significant amounts of water needed for a complete rinse, as calculated in Appendix B. The use of a full cone design maximizes the amount of area that is being sprayed, which is ideal for cleaning. Out of all of the sprayers, the water sprayers require the least specialized head due to the chemical makeup of what is being sprayed. Since water is the least reactive chemical, very basic heads are needed. Mainly, an aluminum head would be the material of choice due to the lower cost and low reactivity with water.

The polishing slurry sprayer (S-202) is the first sprayer on the line that is not purely water. The solution being sprayed by this piece of equipment is a slurry composed of a water and cerium oxide, so more care must be taken when choosing the type of nozzle and sprayer needed for this application. However, due to the scrubbing process, the slurry sprayed onto the glass does not need to be evenly coated on the mirror. Instead, streams of the slurry are poured from thin tubes onto the surface which is then spread by the polishing brushes, as seen in Figure 3.3 below. Therefore, a complete nozzle spray system is not necessary for the cerium oxide mixture and is instead replaced with a simple flow system.

The sensitizer sprayer and silver sprayers are very similar in the equipment used. Just like the other sprayers used in this process, they will be fully automated so that a consistent spray coating can be achieved. The main difference between these sprayers and the previous ones is the type of head that will be used. This is done through the use of a flat spray nozzle, which will ensure that chemicals sprayed on the glass will be in a uniform line across the glass as it moves down the conveyer belt. This ensures an even coating across the glass so that, in the case of the silver, a uniform layer will form over the mirror. The only difference between the sensitizer and silver sprayer is that the silver sprayers will have a dual-nozzle so that the silver solution and the reducer solution can be sprayed at the same time. This is needed to create the redox reaction necessary for the silver to form on the glass, as described in Section 2.7.1. For both of these sprayers, a stainless steel nozzle is used for the chemical resistivity it provides. A PVC nozzle could also be used for the chemical resistivity, however the PVC wears much quicker than the stainless nozzles and would need to be replaced more frequently.

3.6 Scrubbers

The scrubbers needed for glass cleaning are specialized pieces of equipment due to the unique shape of the mirrors being produced. By utilizing rows of cup brushes, as the glass passes under the rotating brushes, it will be scrubbed and cleaned so that a uniform silver layer can be applied to the glass, as can be seen in Figure 3.3 below. The scrubber is mixed with the sprayers of the cerium oxide solution so that a more thorough clean can be achieved. Much like the other sprayer systems, the scrubber unit will include an internal conveyer belt used to move the glass down the line for cleaning. The power required for the scrubbers is 28 kW, as found in Table 2.9a. Scrubber information can be seen in Appendix C.

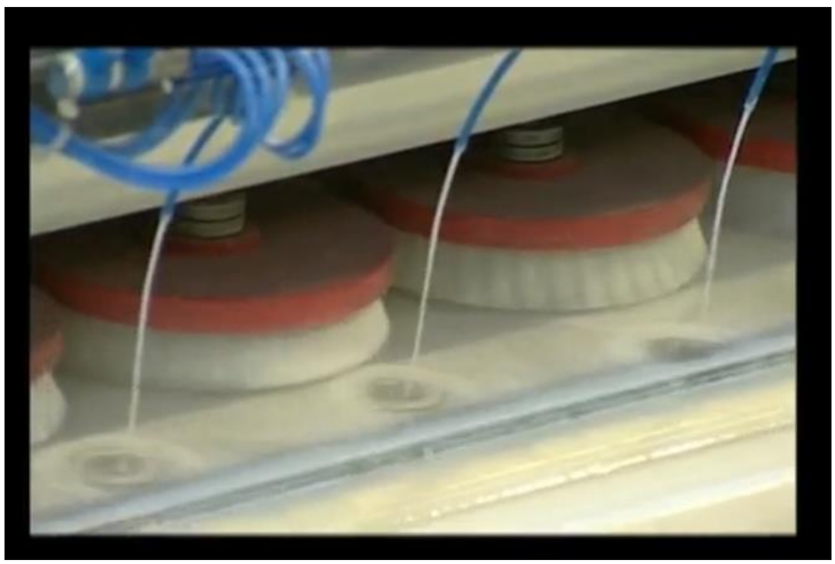

Figure 3.3. Mirror cleaning scrubbers fed with cerium oxide slurry.

3.7 Analytical Equipment

Specialized analytical equipment will be needed to certify that each piece of glass is sufficiently slumped into the required shape after leaving the furnace. As shown in Figure 3.4, shining lasers on the glass and measuring the time it takes can map the contour of the glass with incredible accuracy. By comparing this data to a model of an ideally shaped glass piece, discrepancies and alterations in the glass can seen and measured. All glass pieces must be tested and certified before being sent to Room 2 for silvering, otherwise the glass will be sent back through the slumping process or discarded entirely.

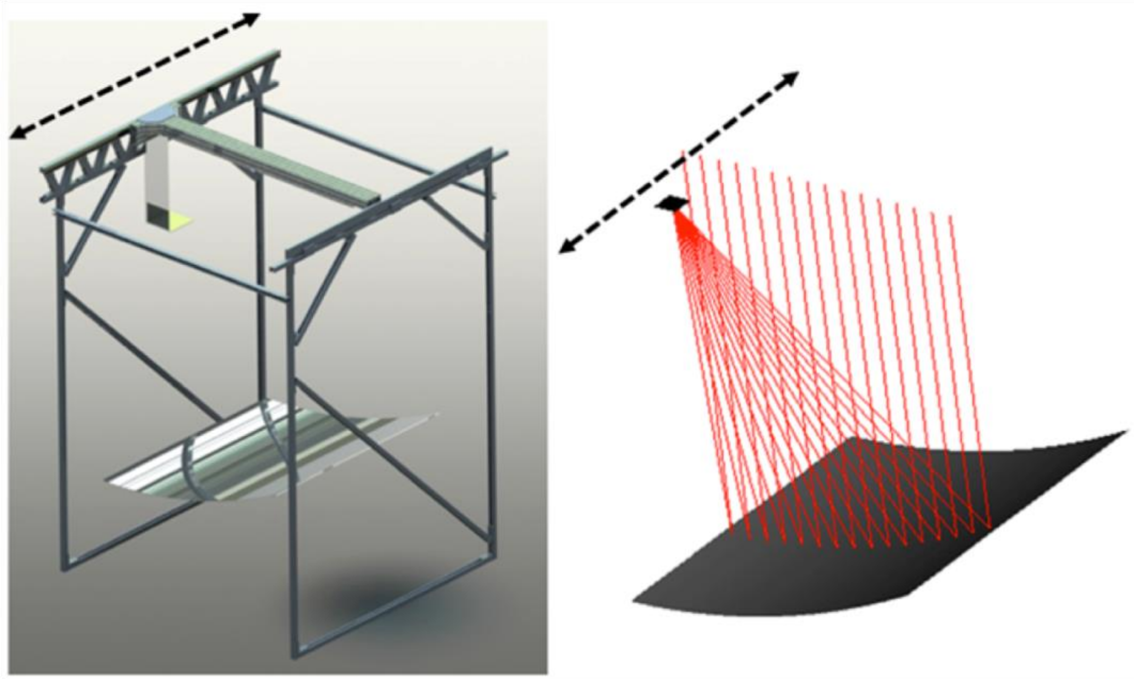

Figure 3.4. Analytical testing equipment for slumped glass.

3.8 Mixing Tanks

Just like the vessels, the mixing tanks will need to have the capacity to mix large amounts of chemicals within them. For an estimated size, each tank should be able to hold an entire days' worth of the mixed chemicals, which ranges from 30 to 3800 liters. These vessels, just like the storage tanks, will be closed top storage vessels with agitators inside of them. The agitators are sized based on the materials in the tank, which only changes slightly between the mixers. The silver solution and sensitizer mixers (M-202 and M-203) all require propellers with five horsepower per 1000 gallons (Seider et al. 580), while the slurry, reducer, and copper lacquer mixers (M-201, M-203, and M-205) require ten horsepower per 1000 gallons (Seider et al. 580). The higher horsepower for these three mixers is due to the solids suspended in the liquid mixture. Like the storage vessels, the materials of construction depend highly on the chemicals being mixed. For all mixers in this process, stainless steel will be used for both the agitator material of construction as well as the vessel material of construction. This will allow a greater lifetime for the mixer as well as a non-contaminated product leaving the mixer.

3.9 Screw Conveyer

Screw conveyers will be needed for three flow streams: the polishing powder, the glucamine reducer powder, and the copper powder. Since all of these solutions are solids, a screw conveyer is more desirable than a pump for these two processes. Also, screw conveyers can be sealed off completely so that contamination is limited for the particles being transported. This is especially important for this process due to the high purity needed of the material being fed in to produce a high quality product. Any contamination in the polishing powder stream would lead to poorly cleaned or scratched mirrors, and any contamination to the copper powder stream would lead to a lower durability of the mirror. The screw conveyers are sized based on the length of the conveyer, as well as the mass of material the conveyer moves. All power requirements can be found in Table 2.7.

3.10 Paint Curtain Coating

A curtain coating paint mechanism will be used to apply the copper and backing paint layers to the mirrors. By using curtain coating, the paint layers on the mirror will be of a better quality than by spraying the paint directly on the mirror. Also, due to the paint being applied in a liquid state rather than an aerosol, the coating thickness can be controlled based on the speed of the conveyer belt and the amount of paint being fed from the coater. Likewise, since the paint will be in a liquid state, the excess run off from the device can be collected under the mirrors and pumped back up to the inlet, reducing the waste produced by this process. An internal conveyer belt is used by this piece of equipment to move the mirrors through the line and ensure an even coating across the mirror. The power needed for these coaters is 80 kW, as seen in Table 2.10.

3.11 Humidifiers

A very important specification needed to produce high quality mirrors is to keep the glass wet throughout the entire silvering process. This begins at the scrubbing stage and is needed until the final silvering has been completed. To insure that the glass stays wet, humidifiers are used to keep the room at a sufficient level of humidity. For a room of 14,000 cubic meters at a relative humidity of 50%, multiple humidifiers can be used which will release 163 liters of water into the air per day. These calculations can be seen in Appendix C. The humidifiers chosen for the plant are made by Essick Air Products, which produce 16.4 gallons of water per day and require 0.135 kW of energy to run. To reach the required humidity, 10 humidifiers will be used in the plant.

3.12 Throttling Valves

For this mirror silvering process, all water used must be of a high purity to insure a quality silver finish. Since all water purification takes place from one device in the plant, throttling valves will be used to distribute the water from the storage vessel to the various areas where it is needed. The use of these valves reduces the amount of pumps in the plant, greatly reducing the power requirements of the plant as well as the capital needed to buy the pumps and their spares. All valves will lower the pressure from 60 psi to 40 psi, which is the necessary water pressure for the rinse spray streams.

3.13 Reverse Osmosis and Deionization System

Water purity is a major factor in the quality of the mirrors produced through the silvering process, so an effective water purification system is necessary for the plant. The incoming water from the utility line goes through a reverse osmosis water purification system initially, followed by a de-ionization system. The reverse osmosis system chosen for the plant is the Res-Kem ML3-55, which removes 95-98% of the ions in the water, and can handle flow rates from 2.19-2.91 gallons per minute (Res-Kem Reverse Osmosis n.d.). Following this system is the Res-Kem Ohm-Tec dual bed deionization system, which can handle flow rates between 2-3 gallons per minute (Dual Bed Deionization Systems n.d.). This system will further deionize the water going to the plant, creating an ultra pure water stream that can be used in the mirror coating process. Further specifications on these pieces of equipment can be found in Appendix C.

3.14 Centrifuges

In order to reduce the amount of utility water that will be pumped into the plant, as well as reduce the waste water produced, centrifuges will be employed in a couple of the waste streams to separate waste solids from the water. Specifically, a hydroclone will be used in order to continuously separate the waste solids from the liquid waste stream. With a waste liquid flow rate of 1.34 liters per minute, only one hydroclone will be needed due to the relatively high range of flow rates that can be handled. The hydroclones will be made out of stainless steel in order to preserve the lifetime of the separator and decrease the reactivity of the water with the equipment.

3.15 Water Heaters

Two water heaters will be used for the rinse spray streams before the sensitizing and silvering of the glass. By heating up the water rinse to 50°C, the glass will reach a temperature of around 30°C after the rinse. This increase in glass temperature improves the sensitizing and silvering process, and produces a better finish on the glass. The power required for these units is 3.50 kW.

4 Safety Statement

As with any process, there are certain safety measures and concerns to be considered within the proposed mirror silvering operation. It is important to known these concerns and to take the necessary precautions to avoid harm to personnel on the plant site as well as to the plant itself. In this process, safety must be considered when handling cuts of glass or mirror as well as when working with the involved chemicals or equipment.

Glass handling is an important safety concern that must be considered at all times, not just during the silvering process. From storage to transport, there is potential for the glass to be damaged, which could pose a threat to those who come into contact with it. Thus, certain safety guidelines must be followed to minimize the potential for glass breakage. First, everyone involved in glass handling should receive the appropriate training to ensure familiarity with the correct glass handling procedures (Collection of Flat Glass 1). This is especially critical in the proposed process because the glass is not tempered, but annealed. As mentioned in Section 5, this makes the glass less durable. It also means that if broken, the glass will form shards with sharp edges, which have the potential to lacerate or puncture the skin. Because it is possible to break the glass every time it is moved, the handling of glass should be kept to a minimum (Collection of Flat Glass 2). When it must be moved, it is crucial to be certain that the equipment used can handle the 27.8 kg weight of the glass to avoid dropping (Mirrors: Handle with Extreme Care 3). When the glass is not in use, the manner of its storage must also be strictly monitored. The glass must be stored vertically on an edge rather than on its front or back because there is more strength through the vertical area and therefore less strain on the glass (Mirrors: Handle with Extreme Care 4). This is especially important for the glass after it has been slumped because the curvature makes it more difficult to distribute the load. Additionally, the glass should only be stored on even surfaces to avoid possible strains (Mirrors: Handle with Extreme Care 4). Lastly, the area where the glass is stored must be cleared of any objects that could fall and damage the glass (Mirrors: Handle with Extreme Care 5). The transport of the finished mirrors must also be considered. Although the mirror coating itself must be protected, the real safety issue in mirror shipment is the potential for breakage. To avoid this, the glass must be packaged such that it does not move within the crate prior to shipment. It should also not be packaged with course materials that could chip the glass edges (Mirrors: Handle with Extreme Care 6).

Perhaps the most important safety concerns in the silvering process are the chemicals used. Knowing the hazards and safety protocol associated with each compound in the process is of the upmost importance to the plant employees. The process itself uses a multitude of different materials. A cleaning agent, sensitizing agent, silver solution, silver activator solutions, reducing solution, copper backing, paint base coat, and paint top coat are all applied to the glass throughout the process. The products and known compositions in these solutions can be found in Table 4.1 below. Some of these mixtures, such as the cleaning agent, sensitizer, silver solutions, activator, reducer, and copper backing must be combined with other materials or further diluted with water to use in the process. Fortunately, these dilutions reduce the concentration of potentially hazardous chemicals in the solutions, making them somewhat safer later on in the process. The formulation ratios for these mixtures can be found in Appendix F.

Table 4.1. Silvering materials and their known compositions.

Product Name	**Role**	**Composition**
Cerium Oxide	Polishing Agent	Cerium oxide (99.99%)
Peacock No. 93 Sensitizer	Sensitizing Agent	Propyl alcohol (20%) Hydrochloric acid (5%) Stannous chloride (5%) Trade Secret (<5%) Water (65-70%)
Peacock HE-300A Silver Solution	Silver Solution	Silver diammine complex (25-30%) Ammonium hydroxide (10-15%) Water (55-65%)
Peacock HE-300B Activator	Activator	Sodium hydroxide (10%) Ammonium hydroxide (5%) Unknowns (85%)
Modified Bahls' Reducer	Reducer	N-methylglucamine Water
Peacock Copper-Tite #3 Peacock Copper Powder	Copper Backing	Toluene N-butyl acetate Copper Metal
Nike-Tech Solar Base Coat (Light Grey)	Paint Backing Base Coat	N-butyl acetate Titanium dioxide Talc Calcium carbonate Zinc oxide Solvent naphtha (petroleum) Butan-1-ol Isobutanol Lead cyanamide
Nike-Tech Solar Top Coat (White)	Paint Backing Top Coat	N-butyl acetate Titanium dioxide Zinc oxide Solvent naphtha (petroleum) Butan-1-ol Isobutanol

The chemicals in these mixtures pose certain safety hazards due to their toxic, corrosive, and in some cases, flammable properties. These properties differ for each mixture and may be found in Table 4.2 below. The concentrated sensitizing solution is toxic if consumed or inhaled. For this process, inhalation is a more serious concern. The inhalation LD_{50} is reported at 8000 ppm (for rats). However, this is not nearly as toxic as carbon monoxide, which has a safety limit at 1200 ppm. Additionally, the Nike-Tech paints contain lead at about 1% of the composition, which is a respiratory hazard, but necessary for its protective qualities in the backing. Still, most solar paint backings contain about 5% lead, so the Nike-Tech paints are considerably safer in comparison

(Demer 2014). Other concerns include the corrosivity of the sensitizer, silver solution, and activator solutions. As mentioned before, these solutions are all diluted with water, which will mitigate this concern. Still, personnel should avoid skin contact with these materials. Lastly, there are a few flammable components in the process. The major concerns here are the lacquer for the copper paint, the base coat, and the top coat, which all have relatively low flash points and should be kept away from ignition sources at all times.

Table 4.2. Toxicity, corrosivity, and flammability data on production materials.

Product Name	**Toxicity**	**Corrosivity**	**Flammable**
Cerium Oxide	No data	None	No
Peacock No. 93 Sensitizer	Oral rat LD50: 5.4 g/kg Inhalation rat LD50: 8000 ppm	Yes	LEL 2.2 vol. % in air UEL 14% *based on propanol
Peacock HE-300A Silver Solution	Oral mouse LD50: 50 mg/kg	Yes	LEL 16% UEL 25%
Peacock HE-300B Activator	No data	Yes	LEL 16% UEL 25%
Modified Bahls' Reducer	None	None	No
Peacock Copper Tite #3	No data	No data	LEL 1.0% UEL 7.6% Flash point: 45°F
Peacock Copper Powder	OSHA Exposure Limit in air: 0.1 mg/m^3 Intraperitoneal mouse LD50: 3.5 mg/kg	None	Yes
Nike-Tech Solar Base Coat (Light Grey)	None	None	LEL 1.0% UEL 11.2% Flash point: 27.2°C
Nike-Tech Solar Top Coat (White)	None	None	LEL 1.0% UEL 11.2% Flash point: 27.2°C

As might be expected with such a variety of chemicals, there is a possibility of side reactions occurring within the process. To reduce the possibility of these chemicals interacting, each stage of the process and its waste streams are separated. In addition, the waste streams are all collected separately. Still, there are certain reactions that may happen within the individual solutions if not stored properly in a cool, well ventilated area. The sensitizer can decompose to create hydrogen in the presence of metal, tin oxides, and carbon monoxide. The activator can also create hydrogen and the silver solution can decompose to nitrogen oxides. Additionally, the paint base and topcoat could form carbon oxides, nitrogen oxides, metal oxides, aldehydes, and other organics if the paint is allowed to burn. The most hazardous side reaction possible in the proposed process takes place between the silver solution and activator solution, which can form silver fulminate if combined in their concentrated forms and left in a warm location for an extended period (Demer 2014). Silver fulminate is an explosive, but this product should not be formed at all if the chemicals are handled correctly. Furthermore, the most dangerous side reaction in this process was eliminated altogether with the choice of reducing solution. Many reducing agents, such as the one provided by Peacock Laboratories Inc., contain formaldehyde in low concentrations. Formaldehyde by itself is a health hazard, but when mixed with the sensitizer, it can form bis chloromethyl ether, which is an OSHA regulated carcinogen. Thus, the process is made considerably safer with the modified Bahls' reducer.

Other potential safety concerns in the process are derived from the equipment itself. Plant personnel should be trained in the safety of each piece of equipment before operation. The pieces of equipment that are of the largest concern are the furnace, conveyer belt, sprayers, curtain coaters, pumps, and storage tanks.

The furnaces are a major source of concern because they reach the highest temperatures present in the process, at a maximum of 1200°C. Because of this, it is important for the area to be marked so that personnel keep a safe distance away from potentially hot surfaces while the furnace is in operation. The glass slumping process is highly sensitive to the furnace temperature, so this must be monitored at all times by sensors within to ensure a quality product. These sensors should also be regularly inspected and calibrated. The blowers in the furnace should also be regularly maintained to ensure an even heating of the glass.

Though the conveyer belts used are a simpler technology, they are some of the most important pieces in the process. The conveyer belt speeds, sizes, and cleanliness, and alignment are all crucial to obtaining a high quality solar mirror. The conveyer belt in the furnace must run at the correct speed to ensure that the glass anneals properly. It must also be free from debris or other contamination to avoid surface defects on the glass. Therefore, speed monitors should be present along the belt and it should be regularly cleaned. Likewise, the speed must be maintained through the scrubbers to get an even and adequate cleaning and through the sensitizing spray to prepare the glass for adhesion to the silver. If the glass is not well cleaned, the silver layer will not bond well to the glass. The same is true if the glass is sensitized for too short or too long a time period. The speed of the conveyer through the silver is perhaps the most crucial to getting an even coating of the desired thickness. The conveyer belt also must be correctly aligned for safe operation. If it is not, glass pieces could be damaged or fall and break into dangerous shards. Conveyer belts can also be dangerous if a loose piece of someone's clothing is caught within the mechanisms. If this occurs, the person could be pulled towards the belt and injured. Therefore, it's important for employees to stay clear of the belts while in motion.

The pumps, sprayers, and curtain coaters are also critical to the silvering process. Because the process deals with hazardous chemicals, any leaks or bursts in these pieces of equipment could release fumes into the facility that could negatively impact those inside. It is therefore important to install pressure regulators in these streams to avoid bursts as well as air quality monitors to ensure that no fumes are released. Besides these safety concerns, the pumps, sprayers, and coaters must all operate at the appropriate pressure and flow rate to ensure a high quality mirror product. Otherwise, the silver, copper, or paint backing layers may be uneven or an unacceptable thickness. To mitigate these potential sources of error, routine checks should be performed and back-up pumps should be available in case of a failure.

Storage tanks can also be hazardous if not treated properly. Tanks should be well ventilated and kept at a cool temperature to avoid pressure build-ups or reactions within the solutions. Storage areas should also be located a safe distance from heat sources or outlets, especially the tanks containing the flammable backings. Due to these potential dangers, it is important to limit the amount of each solution stored on site because the hazard is larger with more solution. Because of this, it is proposed that only a three-month supply of the chemicals be stored on site. This minimizes the amount stored and optimizes the cost of shipping and purchasing the material. With this arrangement, the largest storage tank necessary for chemical components is about 2500 L, as can be seen in Table 2.3b.

Employees must utilize certain personal protective equipment (PPE) during plant operation to protect themselves from the dangers described. When handling glass, safety glasses and steel-toed shoes should be worn at all times. The safety glasses protect against shards of broken glass while the shoes protect the feet from falling objects. The PPE required for chemical handling and working on the process line is more extensive. When dealing with the sensitizer, silvering solution, copper backing, or paint backing, the user must wear a NIOSH/OSHA filter respirator. The respirator can either be a MSA Pink and Green GME-P100 respirator or a GM Magenta and Olive Multi-Gas/Vapor/P100 respirator (Demer 2014). Personnel must go through the proper respirator training in order to operate this equipment. To protect the skin from corrosive liquids, close-toed shoes, body coveralls, and nitrile gloves of a minimum thickness of 0.11mm must be worn. When dealing with chemicals, contact lenses should not be worn. However, chemical safety goggles are necessary to protect the eyes. These may be supplemented with a full-face shield to protect the eyes and skin against chemical spray.

Overall, the process does have certain glass handling, chemical, and equipment hazards. However, the hazards present are unavoidable and others are minimized through the choices made in the process.

5 Environmental Impact Statement

The environmental impact of solar mirror silvering can be limited to three major categories:

1) Water consumption and wastewater
2) Electricity consumption, and green house gas emissions
3) Release of hazardous chemicals

Throughout the process, water consumption is minimal. The larger concern is the release of wastewater, which can be contaminated by the chemicals the water rinses from the glass. Because of this, the environmental impact of water usage is comparable to that of the hazardous chemicals. The overall water use equates to four gallons per mirror resulting in just 400 gallons of water used per day. The average American uses 80 to 100 gallons of water a day, making water use in the silvering of mirror comparable to a four-person household (Water Questions 2014).

Similarly, the environmental impact of the electricity use is significant only in the amount of CO_2 equivalents released in the production of the electricity. For the 8564 kWh of electricity consumed daily by producing 100 mirrors, the green house gas equivalents released amounts to 5.9 metric tons of carbon dioxide daily according to the EPA (Greenhouse Gas Equivalencies 2014). This number may be greatly reduced or eliminated in the future by installing a solar tracking system to produce self-sustaining solar energy for the plant. A REhnu tracker system containing eight mirrors has eight PCU units. Each PCU puts out 800 W of power. Tucson receives an average of 6.57 hours of sunlight a day (Solar Electric System 2013) so each tracking system will produce 42.05 kWh per day of electricity. This means that by installing 204 tracking systems, about 16 days worth of mirror production, all the energy for the process may be provided by solar energy. Greenhouse gasses are also emitted in the transportation of waste and the final product. Tucson is 1060 miles from the waste treatment facility in Houston. Assuming a semi-truck gets 6.5 miles per gallon on average (10 Things 2014), 1.4 metric tons of carbon dioxide will be released per shipment of waste (Greenhouse Gas Equivalencies 2014). The final mirrors will likely be used in Arizona because there is an abundance of sunlight and open land. For this reason, it was assumed that the silvered mirrors are delivered within a 100-mile radius, equating to 0.15 metric tons of carbon dioxide released per semi-truck load of mirrors (Greenhouse Gas Equivalencies 2014).

Thus, chemical waste remains as the largest environmental impact of the process. Chemical waste is produced in the silvering and painting stages of the process. Each waste stream will be dealt with independently depending on the chemicals in the waste stream and the physical state, solid or liquid, of the waste. These waste streams are the cerium oxide used for cleaning, the sensitizer, the silvering solutions, the reducer, the copper backing, and the paint.

The cerium oxide waste, Stream 25, exists as a slurry of water and cerium oxide powder. During the cleaning process, a small amount of silicon oxide is added to the slurry as well as any contaminants that were found on the glass. The cerium oxide particulates can be removed from the slurry using a centrifuge, R-201. Industrial demand for cerium as an ingredient in various pollution control systems is increasing so it is largely possible to sell the used cerium oxide that has gained silicon dioxide for use in applications that will be unaffected by the small amount of silicon dioxide in the solid waste stream (Cerium 2013). The mass of SiO_2 in the waste stream is negligible. Regardless, trace amounts of silicon present have the potential to scratch the glass. The water from this process is recycled into the RO/DI system, R-101.

The sensitizer is applied to the mirrors in large quantities to allow for better adhesion of the silver to the glass. The sensitizer has three known ingredients present in the solution: propyl alcohol, hydrochloric acid, and stannous chloride. Each day, 1.70 kg of propyl alcohol, 0.42 kg of hydrochloric acid, and 0.42 kg of stannous chloride are applied in 218 liters of solution. Both the stannous chloride and the propyl alcohol react with the hydrochloric acid, neutralizing the waste. Permissible emissions to the sewers for all of these substances are controlled on a county level. For Pima County, the only controlled substance is hydrochloric acid, with the concern being the pH of the emissions. Nothing below a pH of 5.0 may be emitted (Regional Waste Water Reclamation 11-19). Because the acid concentration is so dilute in the waste, Stream 45, it may simply be released into the sewage system. For continued emissions of this waste, an industrial wastewater discharge permit must be obtained with a minimum of semi-annual discharge checks (Valencia 2014).

The silvering solution and reducer are applied to the mirrors together. This results in the waste being treated as a single unit. The reducer used in the process contains methlyglucamine and water. The waste will be combined with the silver waste and must be treated as though it contains metal compounds. The silvering solution is a mixture of Peacock Labs Silvering Solution A and Activator B. Together, the silvering solution contains silver diammine complex, ammonium hydroxide, and sodium hydroxide. Because of the presence of the silver diammine and the reaction that takes place to produce intermediates containing silver and then later pure silver, the waste from the combined silvering-reducing spray must be sent to a refinery for silver reclamation. Every day, 4.88 kg of silver diammine, 3.07 kg of sodium hydroxide, and 1.69 kg of sodium hydroxide assuming all the applied solutions run off the glass. The runoff is collected and sent to the Philip Reclamation Services facility in Houston, Texas. The waste will not be treated before shipment (Christensen 2014).

After silvering, the mirrors are treated with a Copper-Tite and added copper powder. The copper powder may not be released to the environment. It has an aquatic toxicity of 0.004 mg/L to Daphina and 0.022 mg/L to rainbow trout, common aquatic toxicity standards. It further is a bioaccumulant with a bioconcentration factor of 108 (Copper MSDS 2012). The copper lacquer also should not be released to the environment (MSDS Copper-Tite 2000). After the glass goes through the curtain coater CC-201 to apply the copper paint, the excess paint will be recycled to Stream 62 and reused, eliminating waste to the environment.

The final product applied to the silvered mirror is a protective paint. First, a base coat is applied followed by a topcoat. The paint base coat contains several harmful ingredients including lead cyanide, naphtha, and zinc oxide. The lead cyanide is a large concern for the environmental impact as is the aquatic toxicity of the components of the base coat, which is coupled with long lasting effects (Nike-Tech Solar Base Coat 2012). Similarly, the topcoat contains zinc oxide, naphtha, and titanium oxide, which are harmful to the environment. Both the base coat and topcoat cannot be released to the environment or drinking water supplies. The aquatic toxicities for zinc oxide and naphtha, which are found in both the base coat and the topcoat, are listed in Table 5.1 below.

Table 5.1. Aquatic toxicity of paint coatings.

Compound	Toxicity to fish (mg/L)	Toxicity to Daphnia (mg/L)	Toxicity to algae (mg/L)
Zinc Oxide	1.1	0.098	0.044
Naphtha	9.22	6.14	No data

Bioaccumulation data is not available for these substances. The paints must be prevented from entering any water supplies, drinking or environmental. The paints are applied using a curtain coating process, CC-202 and CC-203, and the excess paint is reclaimed and recycled to Streams 60 and 61 (Nike-Tech Solar Top Coat 2012).

The previously discussed chemicals are applied to the glass by a spray deposition process. Some of the chemical are released as vapor overshoot, but as the chemicals being used are generally liquids, data does not exist for the global warming potential (GWP) or ozone depletion potential (ODP) for these chemicals in their vapor forms. However, to account for the potential environmental impact of using an aerosol application method, filters have been added to the exhausts of the building to limit the amount of aerosols that may be entering the environment.

The largest environmental considerations for the mirrors once they have been silvered are the land use of solar energy systems, the introduction of lead-based paint into the environment, and the end of life solution for the mirrors. Several steps have been taken to eliminate some of these concerns. The mirrors will be placed into a Photovoltaic converting system upon completion with 8 mirrors per concentrator. The output of the concentrator is 6400 W. Based on current projections, the concentrator produces 60 to 75 megawatts per square kilometer (Concentrating Photovoltaics 3). This is compared to traditional solar energy, which outputs 34 megawatt per square kilometer of photovoltaic panels (A Comparison 2014). Further, the paint backing chosen contains only 1% lead compared to most solar paints, which contain around 5%.

At the end of life for the mirrors, it will be possible to strip the silver off the mirrors and remelt the glass. Hydrochloric acid will be required to remove the silver, but once that has been accomplished, the glass is 100% recyclable. Recycling this glass will have future benefits environmentally. Using recycled glass as opposed to normal glass manufacturing methods reduces the water pollution of the process by half and the air pollution by 20%. It also uses 50% less energy decreasing the overall environmental impact of the process (Feldman 2013).

Overall, the largest impact of the process is the aquatic toxicity of the chemicals used. Using liquid chemicals there is a high risk that the chemicals may end up in the sewer system or bodies of water. Some of the chemicals have aquatic toxicities as low as 0.04 mg/L for algae, which will have a large impact on the rest of the aquatic ecosystem (Nike-Tech Solar Top Coat 2012).

6 Economic Analysis

6.1 Overview

The economic viability of the proposed solar mirror plant is analyzed through several quantifiers, including net present value (NPV), investor's rate of return (IRR), the break-even mirror price and quantity, and the payback period. The financial analysis is guided in large part by plant design cost estimations from Seider et al. (2006). Although this plant will ultimately be only one sector of a larger CPV manufacturing plant, the analysis still provides valuable insight to several cost factors. A brief overview of the results from the analysis are shown in Table 6.1. The plant will produce 26,000 mirrors annually and sell them for $267 a piece. Although the 20-year NPV, IRR, and payback period of the proposed plant in Table 6.1 are not indicative of a highly virtuous venture, it is encouraging that the plant returns a profit every year and has been designed in a way to allow for growth. Thus, there is plenty of potential in the design. In order to drive down the selling price of the mirror, and in turn have a more viable CPV system in the future, the current production must be increased.

Table 6.1. Economic analysis results overview.

Total Bare Module Cost	$2,100,000.00
Total Capital Investment	$4,200,000.00
Annual Costs	$5,600,000.00
Annual Sales	$7,100,000.00
NPV	$1,500,000.00
IRR (%)	23.8
Payback Period (PBP)	8

6.2 Economic Considerations

6.2.1 Total Capital Investment

The mirror plant is a new structure being built in Tucson, AZ, so “grass root” plant cost estimates are used. A three-year start-up period is allocated to establish the necessary facilities, after which a 20-year plant operation cycle is considered. To overcome the difficulty of estimating future price figures, the start-up period is assumed to begin immediately, so all prices are taken from 2014 values. A preliminary estimate of the necessary total capital investment (TCI), which factors in the cost of all the equipment, site preparation, initial start-up, and other investments, is calculated using the Guthrie method. Several approximations are needed to implement this method and obtain rough values for the investment and site costs. Most of these are general approximations taken from Seider et al. (2006). Appendix D shows the use of these approximations and corresponding calculations.

A bare module cost for each piece of equipment is determined to take into account the installation of the device, piping, supporting structures, electrical wiring, and more (Seider et al. 547). The actual free on board (f.o.b) purchase costs are provided from several vendors. Since not all specialized pieces of equipment have listed bare module factors, an estimated factor of 2.45 is used. Sprayers are one example of this. This value provides a general bare module factor for solid and fluid handling equipment. The calculations are found in Appendix D. A notable exception to this method are cost estimations of equipment previously fabricated by REhnu. These price quotations already include the module and installment costs. The most expensive piece of equipment, which also happens to be the most critical, is the slumping and annealing furnace. Along with the molds, it accounts for over 60% of the total equipment costs. This furnace was specially designed from a Department of Energy grant awarded to the Steward Observatory Solar Lab. The original design can only hold one piece of glass, so an economy of scale factor is used to size the furnace up to three glass pieces. This is a suitable assumption due to the scalability potential implemented in the design (Angel 25). This also means that further scaling up will continue to drive down the furnace cost per glass capacity.

When necessary, inflation is accounted for by considering the Price Index value, which was 201.5 in 2006 (used in Seider et al.) and is currently 236.3 in 2014 (Consumer Price Index (CPI) 2014). The entire equipment costing is presented in Appendix D and the total bare module cost is shown in Table 6.1.

One important aspect to note about the equipment obtained from vendors is that they are constructed to coat flat or parabolic mirrors, not point-focus paraboloidal mirrors. The latter will need unique specifications because of the two-way curvature that causes liquid run-off in two directions. This complicates the excess solution catchment mechanisms and the arrangement of the sprayers. The lack of appropriate equipment is due to the nonexistence of large-scale paraboloidal shaped mirror production. Thus, some of the equipment requires special fabrication, which will increase the overall cost. However, it is not expected that these additional costs interfere severely with the analysis posed in this report.

6.2.2 Annual Costs

Several factors influence the annual production cost of the plant. Figure 6.1 shows a breakdown of these factors in more detail.

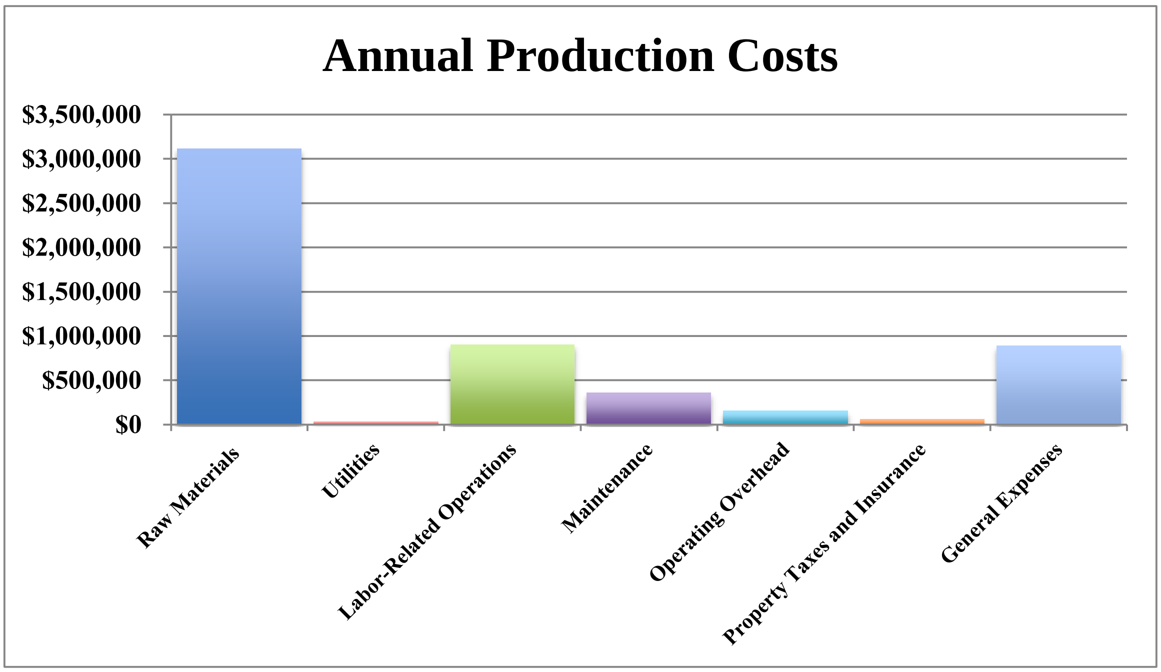

Figure 6.1. Annual production cost breakdown by sector.

The cost of raw materials is determined according to their current 2014 prices. These materials include float glass, silvering solutions, sensitizer, cerium oxide, copper backing, and backing paints. Included in these raw material costs are the estimated shipping costs to Tucson, AZ based on world freight rates. The amount of each raw material needed is based on estimates from the manufacturer, rather than the rough usage rates calculated in the laboratory experiments in Appendix A. The former provides better yield. Since the automated process should have a better yield than a small-scale, hand silvering procedure, this is a valid assumption. The raw materials comprise the largest portion of the annual costs, as visibly seen in Figure 6.1.

The cost of utilities, like water and nitrogen, are also factored into the operating costs. However, electricity is going to be produced in-house through use of the solar CPV systems, which will be purchased the second year of plant operation. During the first year, electricity is purchased from the city. This first year of production will be used to make the necessary mirrors for the desired CPV systems implemented the following year. Based on daily equipment energy requirements of 8560 kWh, the plant will install about 200 CPV systems. The mirrors needed for these systems are taken out of the annual sales for Year 1, and the overall cost of these systems is added to the annual costs for Year 2. Although this may seem costly at first, the use of CPV systems on site provides many benefits. One of the most significant comes from the Arizona Renewable Energy Production Corporate Tax credit (Renewable Energy Production 2014). This program gives businesses with renewable energy systems a tax credit based on how many kilowatt-hours they are generating. These tax credit calculations are shown in Appendix D. The tax credit is implemented into the cash flow analysis.

Figure 6.2 provides a graph of the electricity costs over the 20-year plant lifetime. The blue line represents the cost of electricity purchased from the city. The red line projects the electricity costs incurred by the proposed plant with its CPV systems. The decay in its value is a result of the tax credits. After twenty years, nearly 2.5 million dollars are saved.

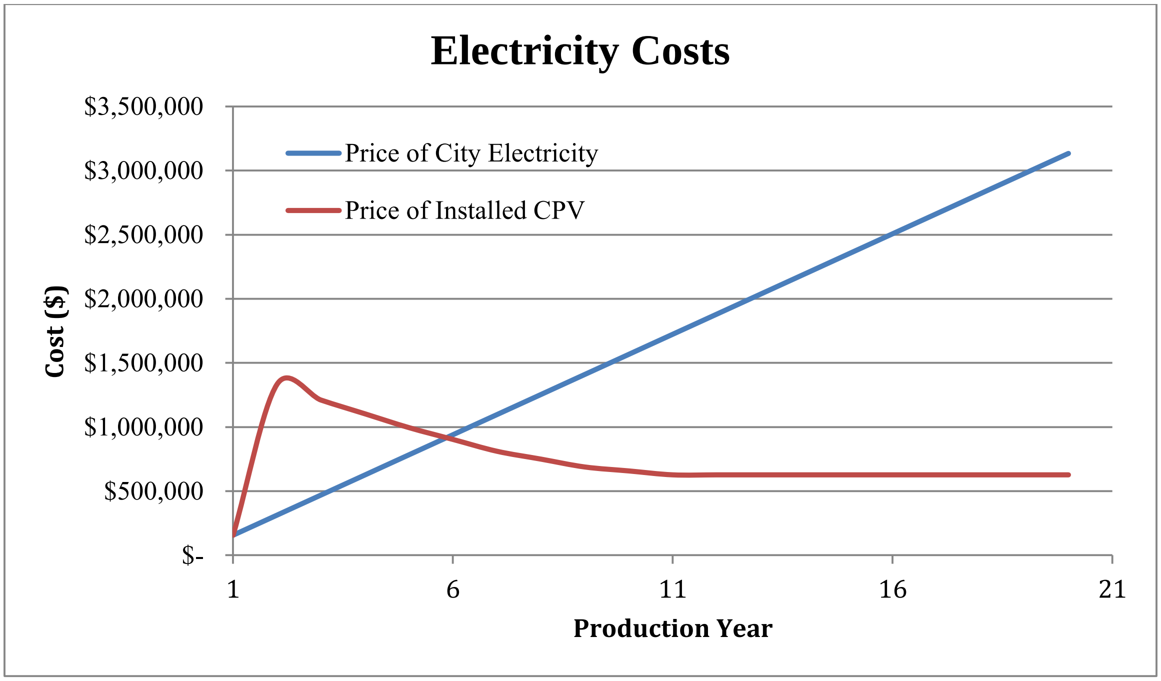

Figure 6.2. Electricity costs projected over the plant lifetime.

The raw material costs, along with the other expenses, are assumed to stay the same every year over the 20-year cycle. However, in reality the annual costs may vary from year to year depending on market conditions. The labor and maintenance expenses and overhead fees are estimated using factors provided by Seider et al., and the calculations are shown in Appendix D. Due to the relatively small production rate in the facility and the highly automated conveyor process, it is assumed that six operators per shift, three in each room, would be sufficient for plant operation. Here, the wages are assumed to stay constant over 20 years, even though benefits and wages for the employees may increase over time. In general, it is assumed that inflation in one area will equally affect the other areas (both expenses and sales will be inflated equally), so there is not much sensitivity placed on the changes in wages or prices (Seider el al. 636). The labor related expenses represent the second largest factor in the annual production costs, as shown in Figure 6.1.

Additionally, depreciation is usually considered in the production costs. However, because this factor varies each year, it is accounted for later in the cash flow analysis.

6.2.3 Annual Sales

The sales revenues are also based on current market prices. The main sources of revenue considered are from the slumped paraboloidal mirrors and residues from the waste silver solution, as shown in Table 6.2.

Table 6.2: Annual Sales

Product	Annual Sales
Mirror	$6,900,000
Silver	$130,000

As mentioned earlier, each CPV system consists of a tracker frame, eight mirrors, and eight power conversion units. It is desired that this system sells for $1 per watt, which amounts to $6400. The mirrors are a considerable expense in that overall system, although the exact share is not known. For approximation purposes, it is assumed that the mirrors account for a third of the selling price, thereby costing about $267 a piece. The silver waste, Stream 55, that does not adhere to the mirror is highly valuable due to the high price of silver. As mentioned earlier, in Section 5, it is shipped to a facility in Houston that can perform a silver extraction. The company receives a credit, which has been claimed to be worth as much as 25% of the money spent on silver nitrate for silvering (Schweig 171). For this analysis, the price for this byproduct is priced as 20% of the total expenditure on silvering solutions per year.

Another byproduct, cerium oxide, may be sold to other industries for some monetary value. Like silver, cerium oxide is a very valuable compound. As described earlier, in Section 2.7.1, the cerium oxide in the process is separated from wastewater using a centrifuge. At this point, the cerium oxide is given away to other commercial industries.

6.2.3 Cash Flow

For long-term viability determination, a cash flow analysis is conducted. This calculates the NPV after every year in the production cycle. The three-year start-up period is incorporated, with an equal portion of the total depreciable capital invested each of those years. The working capital is also invested in the year prior to production. Depreciation, which is the reduction of value of an asset, is an important factor in the cash flow analysis. In this study, a Modified Accelerated Cost Recovery System (MACRS) depreciation method is used over a 7-year class life, which is the standard for glass product manufacturing (MACRS Asset Life Table 2014). At the end of the 20 years, the equipment is assumed to have no salvage value. Additionally, an interest rate of 15% is assumed (Seider et al. 633). This is typical for a high-risk venture. The 15% interest is compounded annually, and the federal and states sales tax, used to find the net earnings after taxes, are a combined 41.5% in Arizona. Calculations for the cash flow are shown in Appendix D. Selected years from the cash flow diagram are presented in Table 6.3 shown below.

Table 6.3. Cash Flow Diagram for Selected Years

Year	Costs	Sales	Discounted Cash Flow	Net Present Value
0	$-	$-	$-	$(1,040,000.00)
3	$(5,800,000.00)	$6,600,000.00	$400,000.00	$(2,930,000.00)
8	$(5,600,000.00)	$7,100,000.00	$400,000.00	$(400,000.00)
13	$(5,600,000.00)	$7,100,000.00	$170,000.00	$800,000.00
18	$(5,600,000.00)	$7,100,000.00	$70,000.00	$1,300,000.00
23	$(5,600,000.00)	$7,100,000.00	$70,000.00	$1,500,000.00

6.3 Economic Analysis

From Table 6.3, the NPV after 20 years of operation with a 15% interest rate is $1.5 million dollars. This low NPV value results from the relatively small difference between annual production costs and annual sales. Consequently, there is a very slow growth in NPV. A greater difference is desired to ensure that the mirror production plant is a profitable venture.

The effect of the small amount of annual profit is seen in other aspects of the cash flow analysis. The payback period, which is the time it takes for the plant to make up its total investments and reach a NPV of zero, is eight years after the three-year start-up is complete, as shown on Table 6.1. That means that profit is not ensured until after eight successful years of operation. However, this number is not as bad as it seems on first glance. Eight years of plant operation corresponds to 208,000 mirrors. This is less than a sixth of what RioGlass produces in one year. This indicates that the demand for such quantities of mirrors exists. In fact, some of the largest solar farms in the world contain close to that amount of mirrors. For example, the Ivanpah Solar Electric Generating System in California has a 170,000 mirror solar thermal system (Strauss 2012). If REhnu and its affiliates are able to shore up investors seeking even a portion of that amount of mirrors, the plant will have higher profitability potential.

The interest rate of return, which is what the interest rate would have to be to return a net zero in the NPV, is 23.8%. This is fairly high, which indicates the high risk of the venture. The anticipated interest rate will be below 20%, so that is another indicator that the plant will at some point succeed.

The aforementioned analysis indicates the importance of considering how much product is being made to the understanding of economic viability. The annual production of 26,000 mirrors and the price of $267 are subject to change as REhnu continues to develop and improve its CPV system. Thus, it is intriguing to study the break-even point, the point at which annual sales equal annual costs, to get a better sense of the prices and production rates that are feasible. Figure 6.3 provides an illustration of this. Anything exceeding the break-even point, the blue line, will return a profit. The red line identifies the correlation between the production and price that has a payback period of three years, which would be highly desirable if this plant operated alone without any other affiliates. Figure 6.3 also shows dashed lines that represent the current production capacity of the plant (26,000 mirrors) and the maximum capacity (31200 mirrors). The maximum capacity originates from the fact that the slumping furnace, the rate-limiting piece of equipment behind the facility, can slump 120 mirrors a day, higher than the 100 mirrors it is currently producing.

With the current production and price, it is clear that the plant will make money. However, operating at a maximum production rate would allow the plant to get closer to the three-year payback line.

In the broader scope of the process, this plant will eventually be part of a larger CPV system production line where the ultimate goal will be to minimize the price of the product and make it appealing to consumers. Judging from where the green line intersects the break-even blue line, it is concluded that the minimum price that the current factory can sell the mirrors for is just above $200. To create the $6400 CPV units, it may be more desirable to sell at a price closer to that of RioGlass, at $85. This would require a production capacity of more than 60,000 mirrors annually, which cannot be achieved by the designed plant unless the slumping furnace capacity is increased.

Figure 6.3. Mirror production versus price correlations.

The goal of reducing annual costs can be realized by other means. In particular, the cost of raw materials, which account for nearly 60% of the overall production costs, can be addressed. Table 6.4 shows the breakdown of the cost of the raw materials in more detail.

Table 6.4: Raw Material Costs

Raw Material	Annual Cost	% of Annual Cost
Float Glass	$1,650,000.00	54%
Silver	$650,000.00	21%
Sensitizer	$220,000.00	7%
Copper Paint	$240,000.00	8%
Backing Paints	$200,000.00	6%
Cerium Oxide	$120,000.00	4%

As shown in the calculations in Appendix D, the float glass is priced at $61 a mirror. This cost is taken from a price quote involving a small purchase order. Buying more items in bulk will lower that cost, which is important due to its sizable impact on annual costs as shown in Table 6.4. The use of some of the other raw materials, like silver and cerium oxide, can also be reduced by optimizing the equipment to prevent excess waste. Interestingly, this is what the general expenses in research are for, so it is likely that the costs will decrease over the 20-year lifespan.

Regarding the other raw material costs, this plant's novel design of recycling water and selling the silver waste is saving over $130,000 a year (see Appendix D). Continuing to further develop these optimizations will drive the annual costs down and allow the mirrors to be sold for less money.

6.4 Economic Hazards

There are many economic hazards associated with this solar mirror production plant. In order to create a more viable plant, the proposed process must have means of handling these hazards. In particular, the main sources of instability with the process come from the cost of silver, copper, and cerium oxide, government subsidies or other involvement, fluctuations in the tax and interest rates, and the future of the solar industry in general.

To begin, the prices of silver and copper have varied greatly throughout the years.

The left graph in Figure 6.4 illustrates this phenomenon, where silver prices ranged from $11.78 per ounce to $48.48. Copper fluctuations, shown in right graph of Figure 6.4, are less erratic. The causes of these fluctuations are due to a variety of factors. There are some investors who view silver as the cheap alternative to gold, and in an effort to secure themselves from the volatile economy, rush to join silver's small market (Petruno 2011). This is leading to unpredictable silver prices. Furthermore, demand for silver is already increasing due to its use in a variety of industries from consumer electronics to jewelry.

Figure 6.4. Silver and copper price fluctuation trends. Source: InfoMine.com

The mirror industry is a particularly small market of silver consumption, which contains the electronics, jewelry, and coin fabrication industries (World Silver Survey 2013). One potential way to allay these concerns is using a different reflective agent. Unfortunately, the most suitable substitute, aluminum, will not reach the reflective quality or environmental damage resistance needed for the solar industry. Instead, consideration can be given to more effective silver solutions that maximize the silver solution-to-mirror transfer ratio. Further consideration can also be given to mechanical deposition techniques, such as vacuum deposition. The equipment for these systems are much more expensive, however their ability to accurately and effectively coat the desired thickness of silver with minimal waste is commendable. In fact, it is often regarded as the best coating mechanism (Hughes 2014).

With regards to copper, similar concerns to that of silver are present. However, there are potential substitutes for copper. As mentioned in Section 2.8.6, a reaction-based copper deposition is a suitable alternative to copper paint. This eliminates the use of copper powder from the process. The concern, however, is with the extra waste generation produced by the chemical reaction.

The cost of cerium oxide is another notable hazard. The price of cerium oxide has grown more than 600% due to its increasing demand and trade quota limits imposed by China, its primary producer (Cerium 2013). Although other polishing agents, such as zirconium oxide, may be used in place of cerium oxide, the latter remains the best polishing agent. Instead, it is vital to further examine ways of reclaiming the cerium oxide from the spent slurries. The recent price increase had lead to considerable research in this field. One optical processing group reported that they have developed a mechanism to reclaim 80% of their used cerium oxide and separate it from harmful particulates, such as silicon dioxide, to remain just as effective (Naselaris). Because much of the research in cerium oxide reclamation has been done within just the last five years, it is anticipated that these recycling methods will continue to become more viable as time progresses.

Another point of concern is trying to predict the government's involvement in the solar industry. It is highly likely that the government will continue to be involved in some manner due to the emphasis on renewable fuels and energy independence. Already, government legislation can ensure a buyer's market by imposing required levels of renewable energy production. For example, in Arizona, the Arizona Corporation Commission has mandated that 15% of its regulated utilities sales must come from renewable energy sources by 2025. In 2010, Arizona was at only 1% (The Age Of Alternative Energy Arrives). Since solar energy is the most fruitful renewable resource in Arizona, it is highly likely that the demand for solar energy will continue to exist.

Other forms of tax incentives exist. This includes the corporate tax credit that was described earlier. These government subsidies and regulations are very helpful to the solar industry. Should this support go away, renewable energies would have a difficult time competing financially with fossil fuels. This is why it is important for solar companies, including REhnu, to continue to the lobby the government for support. Advertisement and promotion of more environmentally safe fuels and energy independence will further increase public support, which is vital for the future of the industry. Also, engagement with universities, like REhnu's partnership with the

University of Arizona, allows scientists and students alike to become actively involved in solar power research. This provides yet another means to ensure growth in the solar sector.

Another issue related to government is the fluctuation of federal and state tax rates. As shown in the cash flow analysis, increasing the combined tax rate would decrease the net earnings and ultimately the net present value of the company would decrease. Increasing the interest rate would also lead to a decrease in NPV. To address this issue, a greater study into all the operational and overhead charges needs to take place. Fortunately, the tax and interest rates should not increase dramatically in Arizona, a traditional conservative state that values lower taxation.

Finally, the solar mirror industry is heavily dependent on the future of the solar industry and the quest for energy independence. The demand for solar mirrors is increasing, but remains volatile from time to time. For example, RioGlass built a mirror production facility in Surprise, Arizona that could produce 1.3 million mirrors a year. However, after running for one year, they shut down because the market is saturated. One way the proposed plant addresses that is by tapering the production. The annual production rate of 26,000 mirrors pales in comparison to larger developers. However, REhnu's current market is smaller and intended for smaller scale farms, consisting of 200 to 2000 mirrors (1.6 MW farms). The current low volume production rate is forecasted to generate a profit, so there is no need to greatly expand production right away. However, as the industry grows and the need to lower the price of the mirrors increases, there is comfort in the fact that the designed process can be scaled up with relative ease.

7 Conclusions and Recommendations

7.1 Conclusions

The goal of the silvering facility is to create profitable paraboloidal reflectors for a CPV solar energy system. The system contains eight mirrors, each one measuring 1.65 m by 1.65 m. To be effective, the mirrors must be at least 95% reflective. This entails the use of silver as the reflective coating, instead of popular substitutes, such as aluminum (Czanderna 10). The facilities are designed to produce 100 mirrors per day.

At an assumed selling price of $267 per mirror, it is determined that the plant will return a profit over its 20-year life span, despite operating below maximum capacity. This suggests that the current design is a viable venture. However, the positive NPV of $1.5 million does not stand as the only criterion for pursuing this design. The mirror's real worth is closely connected to production of the other parts of the CPV system. Ultimately, it may be desired to lower the cost of the mirror, which would require a higher production rate. Because the plant only needs to size up the slumping furnace to accommodate higher rates, this venture is still very promising.

The equipment chosen for this process are optimal components of existing mirroring facilities. Most of these pieces of equipment are sized and priced using vendor information. This introduces a potential source for error. Since a conveyor silvering process does not yet exist for large dish mirrors, the price quotes are for machines handling flat glass. In reality, like the slumping furnace, many of the pieces of equipment need to be specially fabricated to suit this process. Additionally, some of the vendors quoted are retailers from China, which may lead to an underestimate of the equipment cost.

The process has been optimized in several ways to improve the safety and environmental impact of the process. Safety hazards to personnel have been reduced mainly through the choice of chemicals. For instance, a low lead paint and a glucamine-based reducer are used, which are less toxic than the more popular alternatives. When possible, spray guns have been replaced with a curtain coater to reduce the number of aerosols being released into the air.

These safety considerations as well as other choices also improve the environmental impact of the process. The low lead paint has a lasting contribution to the environment when solar fields are producing energy. The curtain coaters also allow the copper paint and paint backings to be collected and recycled, meaning that none of these chemicals are emitted to the environment. When possible, water is also being recycled and sent to the RO/DI system, R-101, for reuse. In the process, no silver waste will be discharged to the environment and all exhaust will be filtered before being emitted. Though there are some remaining safety and environmental risk, they are necessary risks associated with the process that will have lasting benefits of producing clean, cheap, solar energy while using a smaller land area than traditional methods.

7.2 Recommendations

To improve or expand the process for silvering the dish shaped reflectors, several factors may be considered for future work. The current design of 100 mirrors a day may be scaled up. Producing more mirrors requires being able to slump faster. This will be done initially by purchasing a slump mold conveying system that will allow the mirrors to remain on a conveyer when moving between the slumping furnace and the annealing furnace. This will make the process more efficient and produce more slumped pieces of glass in the same amount of time. Further, more furnaces may be purchased to increase the amount of glass being slumped.

To reduce the costs of the silvering process, float glass production may be added onsite. A large portion of the cost of raw materials comes from the transportation of the float glass and could be eliminated. Costs may also be reduced by adding in-house silver waste treatment and cerium oxide treatment in the future. This would save the outsourcing costs for silver waste and allow the cerium oxide to be reused, requiring less to be purchased.

Two of the most critical aspects of the silvering process are the reducer, which creates the silver ion to be deposited, and the paint, which increases the lifetime of the mirror. Further research can be done on adding a base to the glucamine reducer in the future. This may improve the efficiency of the reducing solution and create a better silver coat. While backing the mirror, the paint is currently done by curtain coater application, but there is the potential for using powder coated paints, which may remove paint imperfections around the edges of the mirror.

Finally, the mode of silver application can be improved upon. The current system of a applying the silver using a redox reaction is effective, but not the best possible application. Vacuum deposition of silver gives the best silver plating, but currently is too expensive and not designed for pieces of glass as large as 1.65 m by 1.65 m. Further technology development is needed in order to consider switching to vacuum deposition.

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Appendix A: Lab Report

SECTION 1: INTRODUCTION

Depositing a silver layer onto glass creates a mirror. For solar applications, mirrors must be highly reflective and have an even silver coating. Thus, it is important to have a process that can achieve this. The goal of the following experiments is to develop a reliable, reproducible method for silvering glass using an aerosol reaction with the chosen equipment and materials. This is done in a series of two experiments. In Experiment 1, the silver and reducer are applied via spray bottle. In Experiment 2, the silver and reducer are pressured with a nitrogen canister and applied with a dual nozzle spray gun. The three main steps necessary in glass silvering are cleaning of the glass surface, sensitizing the glass, and finally, depositing silver onto the surface. These are the steps used in the following process. Ideally, the coating will be evenly distributed and reflect most visible light. Discolorations or transparency are signs of poorly silvered glass.

SECTION 2: THEORETICAL BACKGROUND

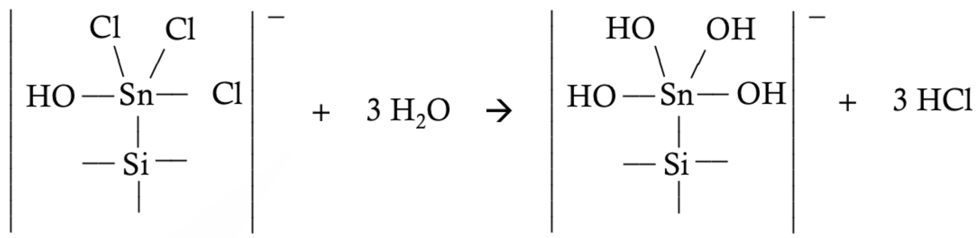
As previously mentioned, there are three main steps in the silvering process, the prepping steps, cleaning and sensitizing, and the silver deposit. Each of these processes has a unique and important role crucial to the production of a high quality silver mirror.

The first step in the process is the cleaning. This step serves to remove unwanted contaminants or impurities from the glass surface. For this lab, a cerium oxide-based polish (Universal Photonics Unicer 166) is being used for the cleaning agent. The cleaner is a blend of cerium oxide and some other earth oxides. It is mixed with deionized water to form a cleaning slurry. The slurry is then used to clean the glass. This works because the slurry has a hardness that is less than that of the silicon dioxide glass surface, so it will not scratch the glass. However, it is abrasive enough to remove the alkali layer and any organics present on the glass surface by scrubbing off a few layers of atoms. After the glass has been thoroughly scrubbed, the cleaner may be washed off with more deionized water.

Following the cleaning, the glass must be sensitized. Sensitizing is necessary in aerosol silver applications because it allows for rapid deposition of the silver. It also helps with the adhesion and uniformity of the silver layer. Though there are many sensitizing solutions available, the common compound present in them is stannous chloride. Stannous chloride breaks down into the sensitizing ion in the following reaction.

$$SnCl_2 \bullet 2H_2O + HCl \rightarrow H^+ + \mathbf{[SnCl_3]^-} + 2H_2O$$

Though the chemical mechanism at this point is uncertain, it is known that this ion then bonds to the glass in a process called “tinning,” creating a complex on the surface. After this reaction is allowed to take place, the glass once must again be rinsed with water. The water is added to the tin complex to remove chloride ions, likely in a reaction similar to the one shown below.



This final complex covers about 20% of the silicon sites on the glass surface. Once this bond occurs, the tin complex cannot be rinsed from the glass surface.

Finally, silvering may occur. The silver plating first interacts with the tinning complexes on the glass surface, forming a sort of interfacial adhesion layer that acts as a center for crystallization for the reflective silver layer. This occurs through a series of reactions that take place when the silver solution, activator, and reducer are combined. The key component in the silver solution is silver nitrate because it eventually reduces to silver metal. First, the compound must be activated, or transformed into the silver ammonium nitrate complex. This occurs in the following reaction.

$$AgNO_3 + 2NH_4OH \rightarrow \mathbf{Ag(NH_3)_2NO_3} + 2H_2O$$

When the reducer is reducer comes into contact with this activated silver, the silver complex dissociates into silver cations. Last, the sugars in the reducer are oxidized and the silver cations are reduced onto the glass surface over the tinned layer as silver metal, forming a silver layer.

SECTION 3: EQUIPMENT

Experimental Equipment: Experiment 1

- 3 Chemical Resistant Spray Bottles – 32 ounces – reducer, Silver, Sensitizer
- 1 Normal Spray Bottle – 32 ounces - Water
- Cleaning Cloths
- 3 Roller Paint Trays – Waste Run-Off
- 1 Chemical Squirt Bottle – Unicer 166 Solution
- 100 mL Graduated Cylinder
- Mass Balance
- Plastic Sheets
- Duct Tape
- Chemicals
    - Silver A Solution
    - Silver B Solution
    - Sensitizer Solution
    - N-methyl-D-Glucamine
    - Unicer 166

Experimental Equipment: Experiment 2

All the equipment in Experiment 1 is also used for Experiment 2. The exception is the addition of a dual nozzle, nitrogen powered spray gun in place of the chemical resistant spray bottles.

- Dual nozzle sprayer
- Nitrogen Tank
- 2, 6-foot lengths of half inch plastic tubing
- 2, 1 gallon chemical resistant chemical storage bottles with half inch outlet
- Nitrogen tank

SECTION 4: PROCEDURE

Experimental Procedures: Experiment 1

1. Solution preparation
    a. Add 250 cm^3 of Unicer 166 to one liter distilled water and mix create the cleaning slurry solution in a chemical squirt bottle.
    b. Combine 16 mL of Peacock Sensitizing solution with enough distilled water to reach a final volume of 16 ounces in a chemical resistant squirt bottle.
    c. Combine 16 mL of Peacock Silver A solution and 16 mL of Peacock Silver B solution. Add distilled water to reach a final volume of 16 ounces. Mix well in a chemical resistant spray bottle.
    d. Add 1.25 grams of Glucamine power to 16 ounces of distilled water and mix thoroughly in a chemical resistant squirt bottle to create the reducer solution.
    e. Fill the standard squirt bottle with distilled water.
2. Glass Preparation and Cleaning
    a. Coat the side of the glass that will not be silvered with clear plastic and tape.
        i. Best seal is obtained leaving about a 0.25-inch border of uncovered glass.
    b. Initially wipe the glass with acetone or ethanol, followed by a water rinse
    c. Scrub with the Unicer 166 slurry solution
        i. Scrub with the solution until an audible squeak is heard over the surface
        ii. Check with a “water bead test.” In a well-polished surface, water should run off smoothly and not bead on the surface.
    d. After the polishing scrub, rinse glass thoroughly until all the cerium oxide solution is removed from the glass surface.
3. Prep work
    a. Prepare the hood by lining with plastic to prevent overspray from clinging to the hood.
    b. Place 3 plastic paint rolling trays in the hood to catch the liquid spray coming off of the glass.

4. Sensitizing
    a. Spray glass with water.
    b. Follow by a lengthy spraying of the sensitizing solution.
        i. Glass must exhibit a soapy residue all over the surface before sensitizer spraying is stopped.
    c. Once the sensitizer has stopped being sprayed, allow the glass to sit for roughly 40 seconds
    d. Rinse the glass is once again thoroughly with water until all sensitizer is removed. The glass cannot dry after the sensitizing spray and rinse or the silver will not bond well to the glass
5. Silvering
    a. Spray Silver AB solution and the reducer solution together at the glass to form the silver layer. Spray continues until a mirrored finish is visible.
        i. Spraying for too long or too short of a time will result in poor silver quality.
    b. Rinse off all silver solution and remove the glass from the hood.
6. Setting the silver
    a. Silver glass is dried with a blow drier until dry to the touch
        i. Blow dryer must be at a low enough setting as to not disturb the wet silver layer.
    b. Remove the plastic backing
    c. Use a laboratory cleaning tissue and ethanol to remove any silver streaking from the front of the glass
        i. This should be done promptly after the silver is dried for best results.
7. Clean up
    a. Pour all chemicals from paint rollers into the hazardous waste container in the hood.
    b. Dispose of all left over liquid chemicals in the hazardous waste container.
    c. Close hood to allow any spills to evaporate.

Experimental Procedures: Experiment 2

1. Solution preparation
    a. Prepare the Unicer Slurry and the sensitizer solution as described for Experiment 1.
    b. Double the amounts of chemicals for the Silver AB solution and the Reducing solution to create 32 ounces of each solution.
        i. Place the Reducer and Silver AB solutions aside. They will later be placed in the prepared 1-gallon chemical storage bottles.
    c. Fill the standard squirt bottle with distilled water.
2. Glass Preparation and Cleaning
    a. Follow the instructions from Experiment 2 for preparing and cleaning the glass.
3. Prep work
    a. Prepare the hood in the same was as it was prepared in Experiment 1.
    b. Test the nozzle to ensure that both chemicals are flowing at even rates.

i. To test the nozzles, fill two beakers with water and submerge the inlet lines into the water. Then spray and ensure the water streams are coming out at roughly the same flow
ii. It is critical that there is at least as much reducer being sprayed as silver otherwise the silver will not be reduced and the glass will be tinted instead of silvered.

c. Attach the tubing between the 1-gallon chemical storage bottles and the attachments of the dual nozzle sprayer.
d. Attach the nitrogen to the sprayer and set to about 60 psi.
e. Add the solutions to the 1-gallon containers.

4. Sensitizing
   a. Sensitize as directed in Experiment 1.
5. Silvering
   a. Hold the nozzle about 2 feet from the glass. Apply strong even pressure to the trigger to release the solutions.
   b. Move the nozzle back and forth, starting at the top and moving down the glass. Repeat moving the nozzle up and down going from left to right.
   c. Once a visible, even layer is deposited, rinse the glass thoroughly.
6. Setting the silver
   a. Set the silver as described in Experiment 1.
7. Clean up
   a. Clean up following the procedure outline in Experiment 1.
   b. Clean out the chemical storage bottles and empty the chemicals still in the tubing into the hazardous waste container.
   c. Fill a beaker with distilled water and use to run any leftover chemicals out of the nozzle.

Experimental Procedures: Reflectivity Testing

1. Mount a laser of a specific wavelength (ex: red laser at 650 nm) so that it shines in a straight beam
2. At the end of the beam, position a photo detector that will measure the voltage of the incoming beam
3. Position a slit over the beam to block the overshooting light and create a point focus on the detector
   a. The beam must be perfectly normal to the detector
4. Measure and record the voltage reading on the detector
   a. It may take a few minutes for the reading to stabilize as the laser heats up
5. Place the silvered glass in between the laser and the detector so that the laser beam hits it at normal incidence
6. Measure and record the voltage reading on the detector
7. Remove the glass from the path and repeat steps 4 – 6 multiple times in order to verify data
8. Divide the measured voltage in Step 6 by that in Step 4
   a. This is the percent of light transmitted
9. Subtract the previous number from one to get an estimate of the reflectivity (assuming absorbance by the silvered glass is negligible)

SECTION 5: RESULTS

See “Appendix A – Results.xls” for all experimental results.

SECTION 6: CONCLUSIONS

Through the experiments, it was found that a good silver coat can be achieved using either a hand spray method or a nitrogen powered spray method. Each method has its advantages and disadvantages. The hand spraying is beneficial for doing small sheets of glass, less than about 6 in by 6 in. If the glass sheets are larger than this, it becomes difficult to apply enough solution quickly enough using this method. When the mirrors are this small, potential problems arise if liquid pools in the paint tray and the mirror rests in the pool.

The nitrogen powered sprayer works well for large pieces of glass. It produces an even coat across the glass and the silver is deposited quickly. With this method, it is important to ensure that the reducing and silvering solutions are flowing out of the nozzles at equal rates or the silver will not be properly reduced and the glass will appear tinted instead of silvered.

For both methods, better mirrors are obtained when the backs were covered. This minimized the amount of silver streaking on the reflective side of the mirror. Two methods were attempted, the first where the tape goes to the edges of the glass and wraps around the edge of the glass. The second leaving an approximately 1 cm border of glass uncovered. The 1 cm border is better because it creates a more flush seal and allowed less water under the plastic. Once the silvering process is finished and the silver is dried, the backing is removed and any silver streaks are cleaned with ethanol. This is best done immediately after removing the plastic backing because the silver is more easily removed if slightly wet. Hydrochloric acid may also work well to clean the streaks off the front of the mirror, but has not been attempted because it is dangerous.

One of the most critical steps in the process was the rinsing after the sensitizing. During the first few trials, a lot of sensitizer was applied, but the glass was not adequately rinsed. In fact, there was visible agglomeration of bubbles after the rinsing. When the silver was subsequently applied, those bubbles created patches in the coating and led to a poor finish. During the more successful trials, the sensitizer was applied for roughly 1 minute, and the glass was rinsed twice as long. After the sensitizer is applied, the tin is firmly bonded to the glass. Therefore, the rinse water does not wash away the tin and it can be applied freely. It was discovered that holding the glass and allowing the rinse to run off more readily helped in the rinsing process. Once the glass is free of droplets but still wet, the silver was applied. This led to a very even finish.

A couple of the mirrors were tested for reflectivity. The results are shown in Appendix A – Results.xls. These mirrors were visibly transparent when held up to fluorescent lights, so a non-ideal reflectivity was expected. The measurements indicated an estimated reflectivity of 62% and 68%, which was very promising.

Overall for continued use and scale up, the developed procedure with a dual nozzle nitrogen sprayer is most practical. Leaving the sensitizer for around 45 seconds yielded the best results. If it remained on for too long, the silver appeared brown and if it was only left on for 30 seconds the glass was highly transparent. The sensitizer must also be fully rinsed from the glass or a scum will form on the silver.

Appendix B: Mass Balances

See “Appendix B – Mass Balances and Stream Table.xls” for all mass balance and stream table calculations.

Appendix C: Equipment Calculations

See "Appendix C – Equipment Calculations.xls" and "Appendix C – Furnace and Humidifier Calculations.xls" for all equipment calculations.

Appendix D: Economic Calculations

See "Appendix D – SolarMirrorEquipment.xlsx" and "Appendix D – SolarMirrorCashFlow.xlsx" for all economic calculations.

Appendix E: Solution Formulations

1. Cleaning Slurry
   - 500 cc Cerium Oxide Polishing Agent Powder
   - Dilute to 2 liters with distilled water

2. Sensitizing Solution
   - 125 mL Peacock No. 93 Sensitizer
   - Dilute to 1 gallon with distilled water

3. Activated AB Silver Solution
   - 125 mL Peacock HE-300A Silver Solution
   - 125 mL Peacock HE-300B Activator
   - Dilute to a volume of 1 gallon with distilled water

4. Modified Bahls' Reducer (Olbert, "Rectangular Mirrors")
   - 2.5 g n-methylglucamine
   - Dilute to a volume of 1 liter with distilled water

5. Copper Backing
   - 1.5 lb Peacock Copper Powder
   - 1 gallon Peacock Copper-Tite #3

Appendix F: Communication Logs

Meeting Log: Tim Forhan
Date: February 25, 2014
Meeting Type: Phone Conference
Meeting Participants:

Timothy Forhan (Worked in glass manufacturing for Ford Automotive)
Elizabeth Forhan
Safatul Islam
Cassie Messina
Tom Zavada

Meeting Start Time: 11:07am
Meeting End Time: 11:39am

Purpose: The purpose of this phone call was to obtain industry perspective on the processing of glass, including but not limited to shaping techniques, advice on silver application, and the tempering process.

Highlights:

Mechanical shaping is often used. Will be a challenge due to the unique parabolic shape of the glass. Would have to be very precise, and could result in a high fail rate. Advantageous in the cooling process as a slump mold covers one side of the glass. How it is done: Fix edges and heat glass until it becomes malleable. Gravity then causes center of glass to sink.

Application of reflective coatings for windows is applied hot. Often performed on the float glass production line. Applying it to the glass hot helps with high adhesion as well as even coatings because glass is very clean on the float glass extruder.

Tempering is done to strengthen glass. Shatters into small pieces (think Correlle plates), but is resistant to breaking. Done by rapidly cooling both sides of the glass, may be possible to run cooling water through mold of furnace to cool back side, air would need to be blown at the other side of the glass.

Possible point of contact: Daryl Middilton

Meeting Log: Blake Coughenour
Date: February 25, 2014
Meeting Type: In person meeting
Meeting Participants:

Blake Coughenour (Grad student working with REhnu and the Optical Science department)
Elizabeth Forhan
Safatul Islam
Cassie Messina
Tom Zavada

Meeting Start Time: 11:45am
Meeting End Time: 12:15am

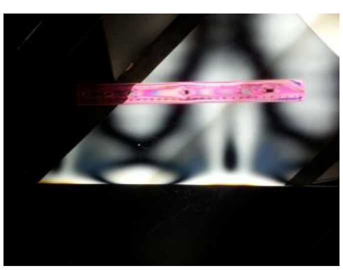
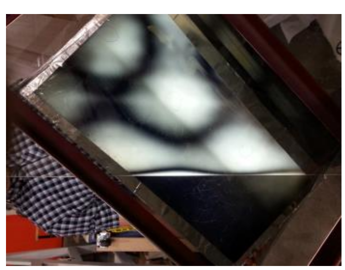
Purpose: To obtain a better understanding of tempering and REhnu's process with the paraboloidal mirrors.

Highlights:

RioGlass tempers, but it is easier for RioGlass. Rio uses mechanical means to form the glass, heating flat sheets and then bending them from the corners. This allows glass to be tempered with a single stream of air.

For paraboloidal mirrors, one stream of air cannot cool both sides, only the concave or convex side. If sides are not cooled evenly, stress deforms surface of glass. Focal point is critical and tempering equipment to temper the glass to ensure equal stresses is very expensive.



Email Log

Date of Email: March 4, 2014
Subject Line: Sales Receipt from Permalac E-Store
Email to: Safatul Islam
Email from: Peacock Laboratories, Inc
Time of email: 12:01 pm

Purpose of email: Confirmation order and receipt for purchase of silvering chemicals

Referenced email:

"Your sales receipt is attached

Thank you for your business - we appreciate it very much."

Sales Receipt:
HE-300 A Silver Solution: 1 gal: $2,985.50
HE-300 B Activator Solution: 1 gal: $390.00
HE-300 C Reducer Solution: 1 gal: $349.65

#93 Sensitizer: 1 pint: $163.20
Copper-Tite Vehicle #3: 5 gal: $371.25
Peacock Copper Powder: 6 lbs: $178.80

Meeting Log

Date: March 5, 2014
Meeting Type: Phone Conference
Meeting Participants:
Safatul Islam
Jim Hughes (General Manager of PrimeNa Technologies)
Roger Angel
Meeting Start Time: 10:00am
Meeting End Time: 10:45am

Purpose: The purpose of this phone call was to obtain information on heat cure solar mirror backing paints and request test samples.

Highlights:

- Suggested use of vacuum deposition to coat silver (‘best results I’ve ever seen’)
- Silver deposits better at slightly higher temperature. Heat glass
- Paint has very good results on paint testing: CASS Testing, Salt Spray
    - Better than Rio Glass Paint
- Only 2 coats necessary. A third coat is available but not necessary
- Paint has ultra low salt content
- Paint can be applied to copper free mirrors
- To coat, use pressurized spray gun
- Apply about 3 mils of coating
- Allow solvent to flash off
- Heat glass up to 290 F
- Then bake paints for 2 – 3 min.
- Can be applied via curtain coating – best way, but equipment is expensive
- Several solar companies shut down, try to gather scrap parts from them
- About 1 gallon of paint needed for each 400 sq ft
- Copper application is difficult

Meeting Log with Frank Demer
Date: March 25, 2014
Meeting Type: In person meeting
Meeting Participants:

Frank Demer (UA safety specialist)
Tom Stahlcup (Design Advisor)
Safatul Islam
Cassie Messina
Tom Zavada

Meeting Start Time: 2:00pm
Meeting End Time: 2:45pm

Purpose: To evaluate the safety considerations and possibilities for the silvering process at the Sunnyside location

Highlights:

- Concern about the amount of overspray released and proper ventilation.
  - Saw need for paint booths
- Students must wear respirators during process
  - MSA Pink and Green GME-P100 respirator
  - GM Magenta and Olive Multi-Gas/Vapor/P100 respirator
- Wanted updated formulations, MDSDs, and exposure limits
- Wanted to see a written JHA for the process at Sunnyside
- Plan a time to do Sunnyside walk through

Email Log

Date of Email: March 31, 2014
Subject Line: Paint Info; From University of Arizona
Email to: Safatul Islam
Email from: Jim Hughes
Time of email: 10:14 am

Purpose of email: Paint pricing from PrimeNa Tech

Referenced email:

Safatul,

Here is the pricing to your location

Base Coat: $51.00/gallon

Top Coat: $55.00/gallon

If you need anything more let me know.

Email Log and Phone Log

Date of Email: April 12, 2014 to April 29, 2014
Subject Line: Md Islam, United States – message for Xinology Glass Products
Email to: Safatul Islam
Email from: Lisa Zhong (Xinology Sales)
Time of email: Multiple

Purpose of email: Silvering Mirroring Line Vendor Quote

Referenced email:

Dear Md,

Specifications are:

Max. glass size: 1650*1650mm
Min. glass size: 1000*900mm
Glass thickness: 4 ~ 8mm
Glass travel speed: 1 meter/min.
Total power: approx. 400 KW
Outer dimension: approx. 95 m long
Total: US$238,400

The line consists of:
Water Wash: $4200, 10 kW, 3 m long
Drying section: $12900, 24 kW, 6m
Sensentizing section: $18300, 15 kW, 5 m
Silvering section: $25600, 15 kW, 5m
Base paint curtain coating section: $16100, 10 kW, 6 m
1st drying oven: $21700, 80 kW, 5.6 m
Top paint curtain coating section: $16100, 10 kW, 6 m
2nd drying oven: $21700, 80 kW, 5.6 m
3rd paint curtain coating section: $16100, 10 kW, 6 m
3rd drying oven: $21700, 80 kW, 5.6 m
Cooling conveyor: $11200, 12 kW

Best regards
Lisa Zhong

Email Log: Jeffry Christensen
Date of Email: April 17, 2014
Subject Line: Silver Diamine Waste Question
Email in String: Two and Four
Email to: Elizabeth Forhan
Email from: Jeffrey Christensen
Time of email: 7:35am, 10:43am

Purpose of email 2: To obtain information about how the University of Arizona handles waste containing silver diamine.

Referenced email:
Elizabeth:

Unless the individual lab includes metals precipitation as the last part of their protocol, there is no metals recovery. Risk Management's hazardous waste facility doesn't have the proper EPA permit, space/technology or time to do metals recovery.

Our disposal vendor does recover metals from the mixed acid wastestream generated by UA. They are able to consolidate UA waste with waste from other generators and do metals recovery on a large scale.

The silver diamine waste would be handled in one of two ways. Consolidated into the organic solvent wastestream and incinerated. Depending on the BTU value of the drum, it may be used as supplemental fuel and doesn't cost as much for disposal.

The waste might be lab packed. Compatible smaller containers are placed inside a drum with vermiculite as a cushion and absorbent. The drum is then incinerated.

UA insists on complete destruction of the material so our future liability is greatly reduced or totally removed. Waste presently goes to a vendor in Houston for routing to ultimate disposal.

Purpose of email 4: To obtain the address of the company in Houston that handles the waste.

Referenced email:
Philip Reclamation Services Houston LLC
4050 Homestead Rd
Houston, TX 77028

Email Log

Date of Email: April 18, 2014
Subject Line: Glass washing machine
Email to: Safatul Islam
Email from: Lisa Lv (Star Glass Machinery)
Time of email: 1:09 am

Purpose of email: Scrubbing Washing machine Vendor Quote

Referenced email:

Dear Md Islam

Glad to get your email.

About the glass washing machine/glass washer. The size 2000MM is suitable for you,.It can scrub and wash max glass size 2000. And after washing, it has heater to dry glasses.

Price is $13200 FOB San Diego

Power 28kW

Please kindly check the quotation attached.

If you have any question, please feel free to contact me.

Thanks and best regards!

Lisa

Email Log

Date of Email: April 18 - 25, 2014
Subject Line: I would like to know more about your Granite/Marble Slabs/Glass Storage Rack,racks for glass sheet,glass safety standing rack
Email to: Safatul Islam
Email from: Kimberly (Sales Manager Foshan Equipment Co, Ltd
Time of email: 5:33 am, 1:03 am

Purpose of email: Storage Rack Vendor Quote

Referenced email:

Email 1:

Dear Md Islam,

Many thanks for your inquiry of glass rack.

According to your requirment, if stock 1000pcs glass, it needs about 20pcs of racks. Each rack is USD840.

I have prepared the quotation sheet for you, please check it in attachment

If you have any query, please feel free to contact me, I will do my best to support you.

Wish you have a nice weekend!

Thanks and best regards!

Kim

Email 2:

Dear Md Islam

Yes we have glass grinding polishing machine also. It is nine motor grinding and edging machine. It can do grinding and polish together. It can meet your needs.The price is $7,900. Power: 19.5 KW

Please see attached quotation sheet

Lisa

Email Log: Steven Valencia
Date of Email: April 21, 2014
Subject Line: Sewer Emissions
Email in String: Eight
Email to: Elizabeth Forhan
Email from: Steven Valencia
Time of email: 9:48 am

Purpose: To obtain Pima County emission regulations for stannous chloride, hydrochloric acid, and propyl alcohol.

Referenced email:

After talking to my supervisor and discussing possibilities we have settled on the following:

http://webcms.pima.gov/UserFiles/Servers/Server_6/File/Government/Wastewater Reclamation/IWC/IWO_No2013-32.pdf

In this ordinance refer to Article III regulated Wastes for an overview of what cannot be put into the sewer systems and at what rate/volume other chemicals can.

As far as Renew would go, if your proposal was accepted and this company/project was created, an industrial wastewater discharge permit would have to be obtained that has parameters that would need to be sampled for at least semi-annually. The parameters would probably be pH, COD,TSS among others. The problem is the hydrochloric acid, so pH would be our main concern.

Hopefully this helps

Email Log

Date of Email: April 22, 2014
Subject Line: Cefla Finishing Group; introduction to REhnu Inc
Email to: Safatul Islam
Email from: Tyrone Kline – Market Manager – Glass/Metal/Plastic
Time of email: 1:37 pm

Purpose of email: Silvering Line Custom Equipment. Receiving Quotation from Italy

Referenced email:

Good day Mr. Islam.
Thank you for your inquiry.
I am in Italy next week and will discuss your inquiry/project directly.
Please contact me via mobile 336.880.0103 after 1:00 pm EST today.
Thanks. TDK

Email Log

Date of Email: April 24, 2014
Subject Line: General inquiry about your Cerium Oxide,oxide powder, factory of Cerium
Email to: Safatul Islam
Email from: Lucy Pang (Yingkou Xingbei Refractory Co)
Time of email: 1:02 am

Purpose of email: Cerium Oxide Vendor Quote

Referenced email:

Dear sirs,
Thank you for your letter.As your request we give your quotation:

Commodity :the best purity of Cerium Oxide (99.999%)
Price : FOB San Diego USD 10000/ton (USD 10/kg)
Payment terms : T/T 100% (quantity < 5 ton)
T/T 30% in advance + the balance 70% against the copy of B/L(Quantity >5 ton)
Package : 25 kg /bag or as your request.
Delivery time : within 7 workdays after receiving your prepayment
Quotation validity: one month

We will give you COA report later.
We hope my quotation will accept you. Please give me your advise .
Looking forward to your reply.
Best regards,

Lucy

Email Log

Date of Email: April 26, 2014
Subject Line: Information on your laser quality test set up
Email to: Safatul Islam
Email from: Brian Wheelwright
Time of email: 9:42 am

Purpose of email: Information on Laser Testing System

Referenced email:

Laser system cost, installed ~15K.

I’d say maybe 10 kW power is a good estimate.

Email Log

Date of Email: April 26, 2014
Subject Line: Information on Furnace, Mold, and Glass
Email to: Safatul Islam
Email from: Tom Stalcup
Time of email: 8:04 am

Purpose of email: Pricing and specs on Furnace, Mold and Glass

Referenced email:

Furnace peak power is 380 kW, and it uses approximately 45 kWhr of electricity per slumped piece of glass. Furnace footprint including control room is 24x20. Cost installed is $450k

The mold cost $65k, and is 68"x68" and is ¾" thick.

Glass Information (from sales receipt)
Vendor: Consolidated Glass Corporation
Attn: Jennifer Segner
Date: 3/26/14

Product:
Glass: 64 15/16 x 64 15/16, 4.0m Solarphire PV annealed

Qty: 75

Unit Price: $61.22

Weight: 4543.2
Total: $4591.50
Boxing: 380.0
Freight: 1283.24

Lead time: 1 to 2 weeks

Email Log

Date of Email: April 30, 2014
Subject Line: Protectoplas Inquiry
Email to: Safatul Islam
Email from: sales@protectoplas.com
Time of email: 1:37 pm

Purpose of email: Mixing Tank Vendor Quote

Referenced email:

Prices for mixers as follows:

MT0100 (90 gal cone) $3,899.00

MT0030 (30 gal cone) $3,361.00

VT1000 (1000 gal flat) $826.99