DESIGN AND CONSTRUCTION OF AN ADVANCED SOLVENT RECYCLING SYSTEM

A Major Qualifying Project
Submitted to the Faculty
of the
WORCESTER POLYTECHNIC INSTITUTE
in partial fulfilment of the requirements for the
Degree of Bachelor of Science
In Mechanical Engineering
By:

Travis J. Simoneau
Date: March 23, 2017

Professor Selçuk Güçeri Major Advisor
Professor Stephen Kmiotek Co-Advisor
ABSTRACT

Large amounts of Acetone and other similar volatile solvents are used in a wide ranging of industrial applications. In most cases, such liquids are commonly used for cleaning purposes and become contaminated with other chemicals, oil, water and small solid material. These solvents are discarded at substantial expense to the producers. In this project, a small –scale-recycling system is designed with the objective of achieving acceptable level of purity for reuse in a cleaning operation.

This paper outlines the design and construction of such a recycling system for acetone as the solvent. The system is envisioned as a compact, totally self-contained and mobile in a way it can be relocated easily depending on the need. The system requires only electric power connection which can be supplied from any 120Volt, 20 Amp source. Instrumentation for unsupervised operation and safety is part of the design process and described in detail.
ACKNOWLEDGMENTS

I would like to thank the following individuals for their support to this project.

- Professor Selçuk Güçeri and Professor Stephen Kmiotek for their guidance, support, knowledge, and enthusiasm as my project advisors.
- Professor Jamal Yagoobi and the Worcester Polytechnic Institute Mechanical Engineering Department for supplying us with the financial support to help us make our project a reality.
- Professor John Sullivan, Peter Hefti, and Patricia Howe for supplying us with the necessary equipment and lab space.
- Barbara Furhman for helping us purchase all of the supplies needed for our project.
- All of the Lab TA’s in the Washburn shops that helped me with all of the machining and welding that needed to be done on the project.
# TABLE OF CONTENTS

Abstract ................................................................................................................................. 1  
Acknowledgements ............................................................................................................... 2  
Introduction .......................................................................................................................... 4  
Calculations ............................................................................................................................ 4  
System Design ....................................................................................................................... 5  
Sensors & Controls ............................................................................................................... 6  
Construction ......................................................................................................................... 7  
Performance and Improvements ......................................................................................... 7  
Conclusion .............................................................................................................................. 8  
References ............................................................................................................................ 9  
INTRODUCTION

Acetone (Dimethyl- ketone) and similar solvents with low boiling temperatures and pressures are commonly used for industrial-scale cleaning processes such as in fabrication of fiber optics, electronic circuits and in preparation of metal surfaces for painting due to its excellent degreaser properties. Its history goes back to middle of 19th Century with the German scientist August Kekule publishing the modern structural formulation in 1865. Acetone is a colorless liquid and typically preferred for its low cost non-toxic characteristics. However, it is highly volatile and flammable, hence needs to be contained in a controlled environment. In 2010, the world-wide production of Acetone was estimated to be 6.7 million tons and U.S. led the production with an annual capacity of 1.56 million tons.

Some basic properties of acetone are as follows:

Basic Formula: \( \text{C}_3\text{H}_6\text{O} \)
Density (liquid): \( 0.7845 \text{g/cm}^3 \); \( 784.5 \text{kg/m}^3 \)
Boiling Point: \( 56 \degree \text{C} \); \( 133 \degree \text{F} \)
Specific heat: \( 2.161 \text{kJ/kg.K} \)
Heat of Evaporation: \( 538.91 \text{kJ/kg} \)
Vapor Pressure: \( 30.6 \text{kPa @ 25\degree C} \)

CALCULATIONS

Amount of energy required to evaporate 20 gallons of Acetone from 20 \degree \text{C} to 65 \degree \text{C}

\[
E \approx (\Delta h_l + \Delta h_{vap} + \Delta h_g) \times M_{acetone}
\]

\[
E = \left(2.161 \frac{\text{kJ}}{\text{kg}} K \times (56\degree \text{C} - 20\degree \text{C}) + 538.91 \frac{\text{kJ}}{\text{kg}} K + 1.47 \frac{\text{kJ}}{\text{kg}} K \right)
\]

\[
\times (65\degree \text{C} - 56\degree \text{C}) \times 20 gal \times 0.00378541 \frac{\text{m}^3}{\text{gal}}
\]

\[
\times 784.5 \frac{\text{kg}}{\text{m}^3}
\]

\[E = 37413.84 \text{kJ}\]

Approximate system completion time of 20 gallons of Acetone assuming 100% efficiency

\[
t \approx \frac{E}{P} \approx \frac{37413.84 \text{kJ}}{2 \text{kW}} \approx 18706.92 \text{s} \approx 5.2 \text{hr}
\]
SYSTEM DESIGN

The proposed AARP system has a capacity of recycling 20 gallons of acetone. It is designed to operate in a batch-mode or continuously using a control system based on sensors information. The complete unit consists of the following components:

A steel tank where contaminated acetone is deposited manually through a sealed cap. This tank also contains a helical heating element made of coiled copper tube of 3/8” diameter and 20” long providing a total surface area of 1.1 ft^2 to heat acetone.

Heating is provided by passing hot water through the heating elements from a 5-gallon hot-water reservoir where hot-water is maintained at 65 °C by a 2000 W, 120 Volt conventional electrical heating elements used in hot-water tanks. This arrangement prevents direct exposure/contact of acetone with electrical elements. Circulation is provided using a conventional high-temperature water pump of 2.1 gals/min capacity.

Condenser is located at the top of the rack to provide gravity-feed for the condensing acetone. Condensation is achieved by passing the acetone vapor rising from the deposit-tank through a condenser coil made of 1/2” copper tubing placed in a cold-water reservoir. A 3/8” copper tube to condenser inlet connects the deposit-tank. Acetone vapor enters the condenser tubes at the high-end and trickles down the tubes as it condenses. Heat removal is provided by immersing the condenser in a cold-water reservoir where water is circulated using a water-circulation pump. Cooling of condenser water is provided by using an air-water heat exchanger similar to an automobile radiator where airflow is provided by a set of small fans typically used in computer housings.

Condensed acetone is collected in a 15-gallon tank, which is also fitted with a disposal valve for removing the clean acetone.
SENSORS & CONTROLS

The system is designed to operate without continuous supervision. Automation is achieved by placing a number of sensors and controllers that are connected to a Control Panel located at the front of the assembly. The principle sensors and their functions are as follows:

**Level Sensor #1** (top position): This two-barrel liquid level sensor is located vertically in the tank for the contaminated acetone collection. It senses both the low and high levels of the acetone in the tank. As contaminated acetone is deposited, its level rises in the tank and when it reaches a certain level, an indicator lamp, lights on the front panel and the purification process starts. This signal also triggers the hot water heating elements and the hot-water recirculating pump as well as all the other elements in the system.

**Level Sensor #1** (bottom position): Likewise, when the acetone level comes down due to evaporation, the same sensor produces a signal when the lower barrel comes to a pre-specified low acetone level. This signal stops the distillation process and shuts off the power for the water heater and the recirculating pumps.

**Level Sensor #2**: This one-barrel level sensor is located in the collection tank for the purified acetone. When collection tank is filed up and a pre-specified level is reached, the sensor signals that the tank is full and an indicator lamp turns on, on the control panel to that effect. It also shuts the system off to prevent any overfilling and/or spillage. A low-level buzzer (beeper) can be added to alert people to the fact that the tank is full.

**Temperature Sensors** (TS): There are three temperature sensors in the system. TS#1 is located in the hot-water tank which maintains the hot water temperature at 65°C by thermostatically controlling the hot-water heater (On/Off). The temperature sensor is also connected to an indicator on the control panel for ease of monitoring. Another temperature sensor, TS#2, is located in the purification tank which indicates the temperature of the acetone being evaporated. This temperature reading can be used as a safety cut-off signal in case the temperature in the storage tank raises above certain level for any unforeseeable reason. The third temperature sensor is located in the condensation tank to monitor the temperature of the coolant water in the coolant reservoir and is transmitted to the front panel as well.
CONSTRUCTION

The system is assembled using a perforated angle-bar structure of dimensions 2’x2.5’x6’ cut from 6’ lengths of angle-bar on an angle grinder chop saw. The angle-bars are held together with corner plates and zinc-plated nuts and bolts. The platform that the tanks sit on consist of a 3/4” plywood. Four 2” wheels are mounted to provide mobility on a smooth surface. The tanks consist of a 25-gallon Buyers Hydraulic Reservoir that has had an additional 1” NPT flange welded onto it, a 15-gallon Buyers Hydraulic Reservoir, and a 5-gallon NorTrac Hydraulic Reservoir that are all screwed and bolted onto the frame. The condenser consists of a custom radiator style 1/2” copper piping angled in a 28-quart storage bin with bulkhead fittings for the acetone inlet and outlet and water inlet and outlet. The unit is self-contained in a way as to the only power needs is a regular, 20A, 120V receptacle. Acetone on the system is completely sealed such that no additional safety measures are needed beyond the customary regulations. A fire extinguisher is mounted on the frame and for accidental spills. A photographic image of the system in near completion is given below.

PERFORMANCE and IMPROVEMENTS

There is a lot of unused space within the system that could be reduced to save room. The system stands about 6’ tall but there is about 1’-2’ of unused space within that height that could reduce the system to a height of about 4.5’. The wheels of the system could be change to be bigger to allow for rougher terrain than just smooth lab floor. In addition to this,
the clearance below the system is very limited to be able to drain the concentrated contaminated acetone. This could be improved again with bigger wheels and by raising the 25-gallon tank utilizing some of the unused height space. The tanks that were bought for the system were cheap ways of filling the requirements of the design, but have many unnecessary additions to them that were fine for the test model. In a more commercialized version of the design, the tank would be custom made to reduce the amount of unused flanges in the tanks and move flanges in more optimized positions for the components that would go in the tank, such as the helical heating element. The main input for the contaminated acetone would also be moved to a more easily accessible position.

CONCLUSION

Because of its low cost and high effectiveness as a solvent, many industries use acetone as a cleaning agent in their processes. Contaminated acetone is often collected in 55-gal drums and is disposed of according to environmental regulations. This often involves a third-party collection of the waste periodically at substantial expense.

A pilot project was undertaken to design and demonstrate the recyclability of acetone that is contaminated in such industrial cleaning operations. Design calculations are based on a 20-gal batch purification, which will purify contaminated acetone to acceptable levels for re-use while significantly reducing the amount of residue, which is anticipated to be about 10%, for disposal. This is expected to reduce the expenses associated with disposal and minimize the environmental impact of waste disposal.

Once the instrumentation is completed, an evaluation of the system operation in a fiber-optics manufacturing plant is envisioned where further data can be collected and additional points of improvement can be identified.
2. Kekulé, Auguste (1866) "Untersuchungen über aromatischen Verbindungen" (Investigations into aromatic compounds), Annalen der Chemie und Pharmacie, 137 : 129–196