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# Aquaponics Automation – Design Techniques

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**Abstract**

Aquaponics operators that have transitioned from hobby to commercial operators have commonly failed to meet commercial expectations. One of the reasons for failures is the occurrence of severe technical errors. Unexpected events can often have drastic financial consequences on new operators, which could be initially operating within tight margins. Standard techniques like Hazard and Operability studies (HAZOP) are conducted by process and chemical industries to do systematic analysis on a process and its sub-systems. Many aquaponics operators are not familiar with these design processes and find design inadequacies after an event, which normally has financial consequences. This design process is able to identify disturbances that could lead to product deviation and identify hazards that could affect the environment. Identifying process issues and designing engineering controls to prevent or mitigate issues can be carried out in multiple forms or design tools. Failure Mode Effect Analysis (FMEA) is one such tool in a designer's toolbox and is recognized as an international standard (IEC 60812), which describes techniques to analyze processes that can effect the reliability of a process plant or determine what possible hazards could be present. The use of FMEA has been utilized by industries to aid in carrying out HAZOP design processes, the use of these design processes can lead to inherently reliable processes. Piping and Instrumentation Diagrams also referred to as Process and Instrumentation Diagram (P&ID) are used in the process industry to show an overview of the process plant. The P&ID also identifies instruments that could be required for measurement and any associated alarms that are present to warn operators and mitigate failures in the process. The use of these design tools have identified and mitigated the risks within the initial design concept to prevent these technical errors with engineering controls designed into the process.

**Keywords:** FMEA, HAZOP, process control, automation, aquaponics

## 1. Introduction

Aquaponics operators that have taken on commercial operations have often suffered large financial losses (Kanae, 2013) during initial operation either from (Consulting, 2010) technical or financial errors. Financial errors such as not planning to obtain market share (product selection and analysis) (Donald) and turnover would not be part of a well-planned business venture. Engineering issues that can cause financial losses from technical issues are engineering problems, which could be designed out of the process with careful planning and design. Utilizing established procedures and tools such as techniques developed by engineers from the chemical/process industry could assist in designing reliable systems. The application of a number of tools that include Process Flow Diagrams (PFD) (Nihal, 2015) to show the major components of the process, is a step in developing process automation and control. A PFD depicts an overview of the process, to show the directions of flows and to aid in further development of the design that is represented on a Piping and Instrumentation Diagram, also recognized as a Process and Instrumentation Diagram (P&ID).

Aquaponics is an industry where Programmable Logic Controllers (PLC`s) and monitoring (Johanson, 2009) have begun to be incorporated, although higher levels of automation such as SCADA or DCS control are not standard. A literature search of industry journals has shown numerous PLC articles yet does not mention higher-level control and supervisory systems. A number of design techniques could be utilized to identify control systems that could be incorporated into the process. To design a functioning process and the associative automation a Process Flow Diagram (Seborg)was used to identify major components that are to be incorporated into the process. This Process Flow Diagram was used as an overview of the process to develop a Piping and Instrumentation Diagram that contains the instrumentation and alarms that the process requires to function in an optimized condition.

The development of these diagrams can be achieved with design processes that can aid in developing these drawings one such process is a failure mode and effect analysis.

## 2. Method

### *2.1 Design Processes*

A Failure Mode and Effect Analysis (FMEA) can be used at various steps in a design process (NPDsolutions, 2016) to identify issues that can effect the reliability of the process. A group of multifunctional engineers or designers that have skill sets in various disciplines could carry out the FMEA. Identifying weaknesses in the process plant design early in the concept and design phase of the project can allow engineering controls to be implemented long before the process is operational. The use of a FMEA can be quite standard and uses a scorecard to identify a Risk Reduction Number (RPN) (Swapnil, 2013). The score identifies areas that can be of concern and where engineering controls could be implemented to prevent or mitigate the identified systems or subsystems of the process. The engineering controls do not necessarily need to be automation controls but could be in various other forms such as additional engineering reviews or mitigating hazards by alternate design.

O – probability of Occurrence 1 very rare – 10 very frequent (Swapnil, 2013)

S – Severity of occurrence 1 No effect – 10 Most severe (Swapnil, 2013)

D – Probability of Detection 1 certain to detect - 10 cannot detect (Swapnil, 2013)

Although the combination of these factors gives an overall score or RPN, the number could still have more weight if there was a stand-alone high number such as the severity of occurrence to operations. A fish kill has been graded at a severity of at least 7 as this could have a significant financial set back to a large commercial aquaponics operation, as the fish could have tens of thousands of dollars in feed invested in them to reach various stages of maturity. It could also take the operator some months to recover if the operator is staggering (Nick, 2005) the fish batches to keep a constant turnover over the whole year.

The FMEA review results were documented into a table to record any responses and to determine the RPN score. Design notes were also taken at this stage as the analysis also identified possible design solutions. Recording the outcomes of the analysis will aid in the design process as it allows for validation data to be collected that can be referred to for verification as the design develops.

### *2.2 Failure Mode and Effect Analysis on an Aquaponics Process*

An FMEA in a design phase is normally carried out by multidiscipline team member's, yet as this design is being carried by a single team member an alternate approach is required. Sources from existing operators that have experienced failures or reported issues with their aquaponics systems (past history approach (NPDsolutions, 2016)); will be incorporated into the analysis to obtain a better understanding of failures. The FMEA could design controls that would aid in the prevention of these incidents, or finalizing selection of the major components could benefit the reliability of the project and reduce risk (Adrienne, 2012) for the long-term goals of a project. The results are to be reviewed with a current version of the Process Flow Diagram that is being used to develop an initial design concept.

Table 1. Examples from Failure Mode and Effect Analysis

| FUNCTION | FAILURE | EFFECTS | S | CAUSES | O | CURRENT METHOD | D | RPN | DESIGN NOTES |
|---|---|---|---|---|---|---|---|---|---|
| Maintain Dissolved Oxygen | Aeration System | Kill Fish/Plants | 7 | Mechanical Failure or maintenance downtime | 4 | None | 2 | 56 | Using Compressed air as it can be stored allowing for failure to be repaired without loosing fish eg. 2 Compressors for redundancy |
| | Anearobic conditions | Kill Fish | 7 | System dead spots / anearobic zones | 4 | None | 8 | 224 | Select air driven processes / additional DO instruments / Investigate diffuser technology |
| | Power Outage | Kill Fish | 7 | Mains Outage / total loss | 7 | None | 1 | 49 | Install Fail to open/close valves to divert oxygen/compressed air to fish tanks during power loss |
| Store Fish | Oils Catch | Injury | 10 | Hazardous | 1 | None | 8 | 80 | Design System to automatically start fire drench - Storage Area (SIS) / to |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Feed | Fire | | | Area (oil) | | | | | have Hazardous Area assessment as part of design |

The results of the FMEA (Table 1) highlighted some safety issues that also need to be addressed in further analysis such as a hazardous area review for the safe storage of fish feeds that contain oils. It also identified some changes that could be implemented to increase reliability of the process, either by redesigning subsystem components or by adding additional instrumentation to monitor identified process limits, yet also design techniques to control the limitations.

Table 2. Examples from Failure Mode and Effect Analysis

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Feed Fish | Gas buildup | Injury | 10 | Lack of Ventilation | 2 | None | 3 | 60 | CO2 Air monitoring to alarm |
| Fill/Clean Tanks | Ammonia / Nitrite build-up | Kill fish | 7 | pH or temperature shocks to system | 4 | Monitoring | 2 | 56 | Allow additional sizing in nitrification to handle system shocks |
| | Effluent Spill | Kill wildlife | 6 | Tank Failure | 1 | None | 3 | 18 | Add Bunding Drainage storage to be sized to contain largest tank volume |
| | Empty Tanks | Kill fish | 7 | Process Failure | 4 | None | 2 | 56 | Add low level monitoring and alarms to DCS also add audible alarms |
| | Solids build-up | Kill fish | 7 | Pump failure | 1 | None | 4 | 28 | Flow switch from solids removal to provide alarm |
| | Overfill Tank | Kill fish | 7 | Pump Return Failure | 3 | None | 2 | 42 | Use overflow return line / gravity fed |
| | Fall in tanks | Drownin g | 10 | Accessible Heights | 1 | None | 4 | 40 | Full review of all access to incorporate handrails/barriers where appropriate |
| Mineralis-ation | Water Quality | Kill fish | 7 | Total Dissolved Solids | 3 | None | 2 | 42 | Add monitoring of solids / mineralisation - automate solids removal |
| | Water Quality | Kill fish | 7 | Total Suspended Solids | 3 | None | 2 | 42 | Add monitoring / add stream diversion to utilise inline filter to remove suspended solids |

### *2.3 Automation and Aeration Control Strategies*

The FMEA results (Table 1 & 2), has highlighted that there are many instrumentation and controls that could mitigate or prevent some of the technical failures that have occurred in aquaponics processes in the past. One of these highlighted was the use of aeration within the process as it can be stored as a reserve during a power outage. The other is that the stored air could be utilized to operate multiple parts of the process to prevent anaerobic conditions. This could allow some innovation to take place and adapt technologies mainly used in process plants and/or the wastewater industry to carry out similar functions.

The process control industry has used Fail Open (FO) and Fail Close (FC) valves (Marlin, 2005) to return a process to a safe state during a disturbance or failure to the process. A simple relay or contactor that is energized by the mains supply could control an extra low voltage supply that feeds a solenoid, when power is lost to the process the contactor de-energizes returning the Fail Open valve to a position where air could flow from the stored air in the compressed air bottles. This could supply additional dissolved oxygen to the fish tanks for short periods, until the power is restored or an emergency source could be provided.

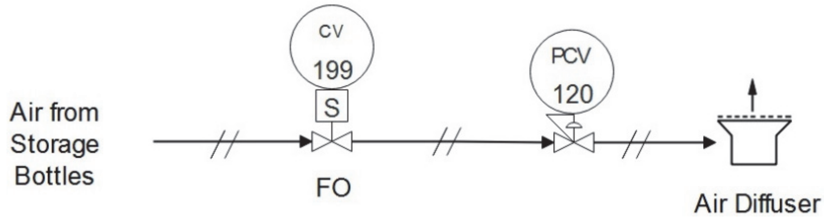


Figure 2. Fail Safe Design

Aeration techniques have been developed in the wastewater industry and in many circumstances would be required to operate in harsher conditions than what would be expected in an Aquaponics environment. The use of diffusers have had large amounts of research and development applied to them to supply the wastewater industry. They are able to supply a range of bubbles with varying sizes, which alternately can reduce power usage as the bubble size optimizes gas exchange. The aquaponics process relies on Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) (Endut, 2012) throughout the process for materials to be converted or broken down into usable forms for plants. Diffusers suitable for this application could be utilized to supply this gas exchange. Automation could be configured to supply dissolved oxygen as required (bubbles) with the use of measurement and active control from a SCADA/DCS system. The system could control an output determined by the measurement of dissolved oxygen levels from instruments placed in areas with expected BOD and COD.

In plant beds, disease such as Pythium can be caused by anaerobic conditions, which are present when (Sutton, 2006) less dissolved oxygen is available. Disease can also be caused by higher temperatures in the aquaponics/hydroponic solution that lead to lower levels of oxygen being present. Traditionally aquaponics growers will install air stones, which will dissolve oxygen into the aquaponics solution, although there are diffusers that are able to supply ultra-fine or fine bubbles (Kossay, 2006) that have an overall greater surface area that maximize gas exchange. The use of evenly spread diffusers within the floating beds would be able to supply an evenly spread amount of gas exchange, lowering the risk of anaerobic conditions developing in isolated positions of the beds.

2.3.1 Instrumentation Adaptation

The FMEA (Tables 2) also identified that there could be a requirement to monitor some of the parameters that are in the aquaponics process, which could include adapting instrumentation technologies that were developed for the wastewater treatment process plants.

The FMEA (Tables 1 & 2) identified features that could be incorporated onto the P&ID such as instrumentation used to measure solids for the measurement of Total Dissolved Solids (TDS) and Total Suspended Solids (TSS). The TSS in an aquaponics system is required to be monitored but also kept in control as the solids "cause sub-optimal water quality characteristics" (Danaher, 2009). Having monitoring within the process plant allows processes not only to be monitored but also adjusted to known researched ranges that are optimal for production. This could be by streaming parts of the process that contain solids to a sub-system that is designed to remove excess solids from the process. As the PFD for this proposed design currently has an inline filter for the process, an additional flow path will be added. The addition of this flow path will allow the effluent to bypass the main flow to filter out suspended solids if they exceed recommended values.

Instruments that monitor solids are commercially available and development has been mostly refined to meet stringent regulations, required by the wastewater industries , which can be (Tom Davies, 2017) "accountable to a range of state authorized bodies such as Department of Environment Regulations (DER) and Department of Health (DoH)". These regulations include the accurate measurement of contaminants to meet drinking water standards. The instruments that are available on the commercial market is capable of monitoring TSS down to or lower than the 1 mg/L range. Various makes and models that are able to supply (Teltherm Instruments, 2017) (BTG Australia Pty, 2004) complex features with local displays and built in relays that are able to trigger local alarms. The measurement of TDS has also been developed mainly for use in the wastewater industry and can be in various ranges with resolution of 1 ppm or lower not uncommon. Monitoring the TDS and TSS in the system would be related to the amount of solids that are introduced into the system. As the current process design has a mineralization tank that contains the solids, an additional sludge level-monitoring instrument will be added to the design. The sludge level monitor has a controller with programmable outputs, which could be utilized to operate a filter to remove excess solids and prevent the dissolved solids from exceeding optimum levels.

## 3. Discussion

The FMEA also identified other risks to the process plant and impacts to the surrounding environment. It was documented in the FMEA that aquaponics systems could result in spills from failures in the system. Where possible gravity feed will be used to supply the system and pumps would only be used to supply flow if there was a requirement to boost pressure or pump back uphill in the process. The use of bunding was also documented to contain liquid in the greenhouse or water treatment areas (EPA, 2017) to prevent nutrient rich water from entering the environment. The bunding could be a simple curb structure surrounding the process area. With the addition of a sump drain and pump installed in the floor area, the liquid could be easily removed after a spill event.

The FMEA also identified that if there are shocks to the system such as changes of temperature or pH imbalances, there would be reduced optimization in the nitrification process, which could lead to ammonia and nitrites reaching excessive levels. The calculations to size nitrification tanks and the relationship with protein (FAO) entering the system are extensively documented, however allowing this component of the system to be oversized could prevent toxic buildup of ammonia or nitrates if the system was exposed to unexpected or uncontrollable system shock events (such as temperature change). The FMEA also documented that there are hazards in the process such as Carbon Dioxide that is heavier than air. The accumulation of concentrated gasses could injure workers in the process and could go unnoticed until an incident took place. Other hazards to the process that required monitoring also bought about some additional instrumentation to control the parameters before they re-entered the process plant, allowing the ranges downstream to have an additional layer of control upstream in the process.

The FMEA also documented results for further consideration as the design begins to develop such as handrails around floating beds, which would be further considered if the tanks were recessed into the floor.

## 4. Conclusion

The results have identified that there can be forms of risk mitigation to the processes that could be incorporated into the design. These include passive devices, which could be in the form of measurement and control with the use of instrumentation, or active control devices to maintain the process within required ranges. The FMEA also identified passive fall prevention devices in the process plant such as handrails in areas where they would be appropriate.

This analysis also identified that barriers such as bunding in the form of curbing could contain spills and prevent nutrient rich water entering water supplies. After further investigation, it was determined, that it is a regulatory operational requirement in some areas.

The FMEA results have shown that there could be some additional analysis done on the process plant to determine if an appropriate hazardous area or regulations for correct storage should be included in the design of the process. This design process however is only one tool that could be used to identify hazards to the process and is only identifying inadequacies that are in the current concept stages of the design. This design activity should be repeated at the detailed design stage using the current documented results to check if the identified responses have been incorporated into the design. Additionally as the design develops, there could be unforeseen risks to the process that were not present or identified during the concept stages of the design. This process should also be carried out before the commissioning stages of the process plant as the commissioning process can have a very different set of risks to the process plant that must be considered before introducing fluids or forms of energy to the process plant, which have their own set of associated risks.

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