LESSONS FROM 20 YEARS WITH PLANT ELECTRICAL AND CONTROL SYSTEMS

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ABSTRACT

Waste Solutions, now a division of CPG NZ Ltd, has specialised in the design, upgrading, control and operation of municipal and industrial, water, waste treatment, waste to energy plants and reticulation systems for over 20 years. During this period staff have had the opportunity to observe and learn from a variety of plants and clients, both public and private, in a number of areas of the world.

This paper considers both general and, more particularly, some electrical and control lessons learnt during the last 21 years the author has had in the design and operation of such plants, and reviews these in a way that we hope others will be able to learn from our experiences.

KEYWORDS

Automation, control, power supply, hydrogen sulphide (H2S), signal earthing, 24 V dc power supply, signal surge protection, analog input protection, electrical hazardous areas

1 INTRODUCTION

The length of association with water and wastewater projects in particular has resulted in some insight into the ergonomics of plant design, particularly in the control system. Ongoing involvement with facilities has allowed us to identify the implications of decisions, and to identify solutions that work, as well as areas of risk.

2 ON-SITE OBSERVATIONS

Some of the observations made over the years come from trying to get the information required about particular plants when preparing upgrade or remedial work plans:

- The operators are the only ones who REALLY know what is going on at the plant;
- The temperament and busy-ness of most operators leads to a disinclination to writing their observations down. They will talk among themselves and share information, but it doesn't usually reach paper.

Wandering around on site, making observations, asking questions of the operators and noting the answers appears to be the best general way of getting useable operational information. Onsite instrumentation usually gives consistent answers, but it pays to check the instrument results are credible before believing them. How often is a Dissolved Oxygen (DO) or pH meter checked? Is the pipe to a mag-flow type flow meter always full? Do the readings from an ultrasonic distance measuring sensor above a flume or tank always give credible results? For each of these we have seen readings that have been dubious, but which were nonetheless used to control plant operation.

For instance, if a DO meter is used as part of a control system to regulate aeration of a waste pond, (an increasingly common strategy for reducing power costs) and the DO meter reads low because it has a biofilm on the sensor face, because routine cleaning has not been performed, then money will be wasted by raising the DO unnecessarily. We wonder how many local authorities have this or similar situations happening every day.

It is better to design and build out problems than to try and fix them later. This may seem obvious, but we regularly visit sites where there have been several "upgrades", where each upgrade is technically 'safe', but where earthing and earth bonding arrangements have not been coordinated between upgrades, with subsequent frustration that neither the original nor the new systems are as reliable as expected due to this issue.

3 SIGNAL EARTHING

One of the most frequent and persistent electrical problems found on sites, particularly sites spread over a large geographical area, is the degradation of signals due to interference from poor earthing and bonding practises or coordination. This degradation sometimes destroys confidence in the information upon which to make operational decisions because the item being measured seems erratic or unrealistic.

While switched control signals are not usually affected because of the relatively high voltage these operate at, signals from sensors are usually much smaller voltages, and if these have additional, mains frequency signals added to them as interference by poor earthing practises, the result can frequently be unreliable or 'wandering' readings on the SCADA (Supervisory Control And Data Acquisition system) or Programmable Logic Controller (PLC). Particular attention should be paid to earthing and bonding practice and to ensure coordination between old and new work, and between spread out sections that must communicate with each other for control or SCADA purposes. Use the "star" principle for earthing, and 'group' the various earthing requirements (24V dc bus earthing, sensor signal return earthing, machinery power earthing, general bonding, signal screening earthing etc and tie these back individually to the 'star' point). The earth itself may consist of several amalgamated earth stakes / buried radials, as long as these are terminated at the central start point

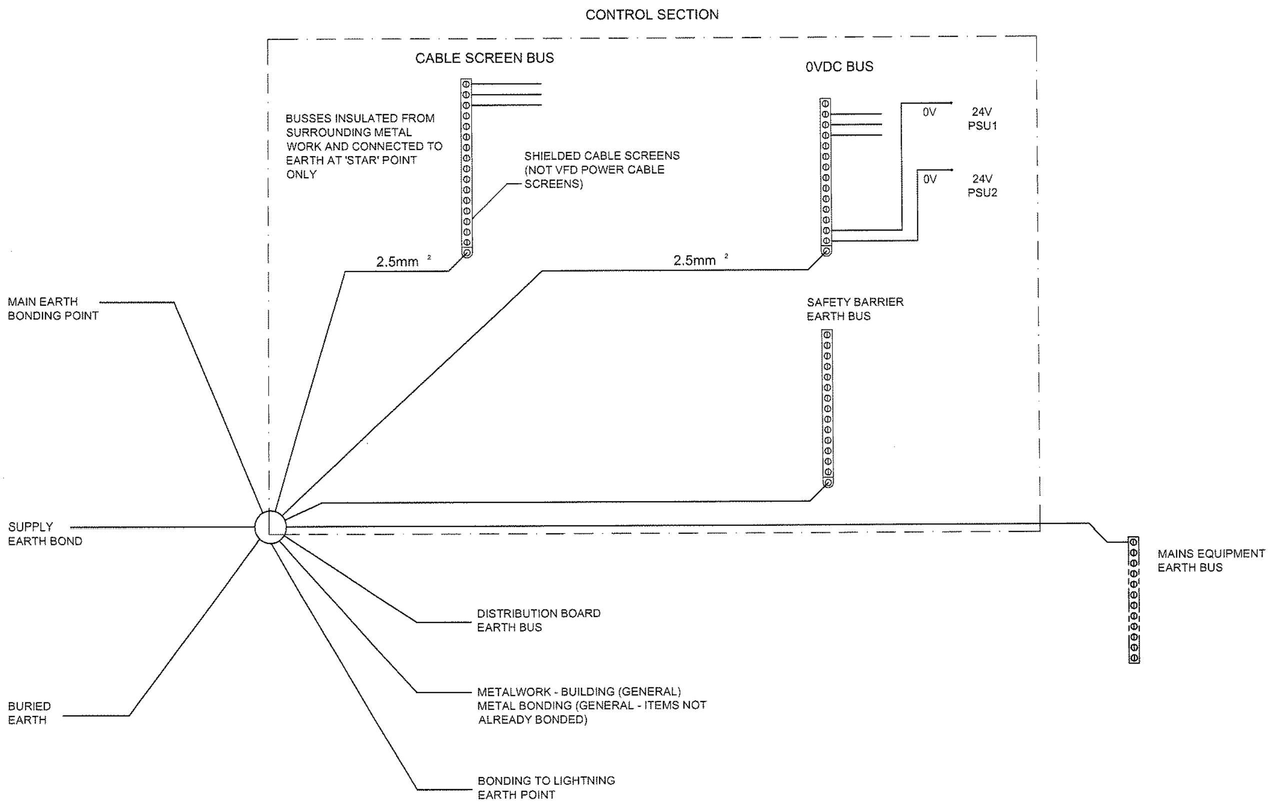


Figure 1: Generic earthing system diagram; "Star" topology

Lesson: If crossing between several separately earthed sites is unavoidable, then it is best to 'galvanically isolate' the signals travelling between sites by means of isolators, relays, radio links, or, in the case of digital signals, fibre-optic links. Galvanic isolation means that there is no conductive connection between the two points, they are electrically insulated from each other while still allowing the wanted signal through.

Example: Sludge blanket level sensor at a clarifier which required a separate earth bond to the ultrasonic probe holder. It was connected up according to the manufacturer's manual, but needed the extra earth bonding connection.

4 MAINS POWER SUPPLIES

Waste water plants, more than any other public facility, are a 24/7 operation, and plant failure is increasingly untenable. You can't tell people to 'stop going please' while you fix the plant; it just keeps coming, so any measure that improves the chances of undisturbed operations must be considered. Once duty standby systems have been mechanically set up, some thought needs to be put in to the reliability of electrical and control systems.

Many Waste Water Treatment Plants (WWTP) serving smaller communities use fairly large areas of land based ponds to treat domestic waste, and for these, a power loss may be of minimal importance. It may just mean the loss of a surface aerator for the duration. Waste still flows through the plant by gravity.

As the served population size increases, the land area required for such a treatment process becomes prohibitive and more energy intensive methods are used to treat the waste such as mechanical aerators or anaerobic digesters. A loss of power to these larger systems can quickly become a problem, including the loss of monitoring facilities to even be able to tell what flows are entering or leaving the plant.

In the past, mains power supplies have generally been very reliable. We recently did an analysis of power losses for 4 large pumping stations to assess the need and likely running time for standby power generators (Tables 1 & 2).

Table 1: Tabulated results from a study on power outages for 4 pumping stations

Pump Station	#1	#2	#3	#4
Number of Outages longer than 2 minutes	9	13	9	7
Average length of outage	3.05 hrs	1.82 hrs	1.3 hrs	1.2 hrs
Total no-power time	27.5 hrs	23.9 hrs	15.62	10.5 hrs
Period covered (years)	11	9	9	7
Percentage time power available	99.97%	99.97%	99.98	99.98%
Longest no-power time	11.9 hrs	6.0 hrs (planned outage,)	2.6 hrs	2.1 hrs

Table 2: Tabulated spread of outage times

Outage period	#1	#2	#3	#4
<5 mins	1	1	2	1
>2min, < 1hr	3	6	0	3
> 1 hr, < 2 hr	4	3	5	3
> 2 hr, < 3 hr	3	2	3	2
>3 hr, < 8 hr		2	0	0
>8 hr	1	0	0	0
Totals	12	14	10	9

The data shown in table 1 & 2 covers a period of time varying from 7 to 11 years. These figures were taken from power network records, but the more recent ones were corroborated by telemetry logs from the area scheme managers.

It should be noted that this area is fed most of its power via a very long piece of 'wet string' from Christchurch. Considering this, the above power loss figures are remarkably good.

It can be seen that the majority of power breaks were less than 2 hours long, so, provided there is sufficient storage for incoming flows for two hours, a power loss of less than this should not be a problem. The average outage is roughly 2.5 hours per year; not that this is any predictor of what might really happen!

However, flows are increasing, authorities are becoming more 'risk averse', and the public less tolerant of Resource Management breaches; so emergency power generation is being installed in this instance as one more step to avoid 'unauthorised discharges' coming from any flooding wet wells or the like.

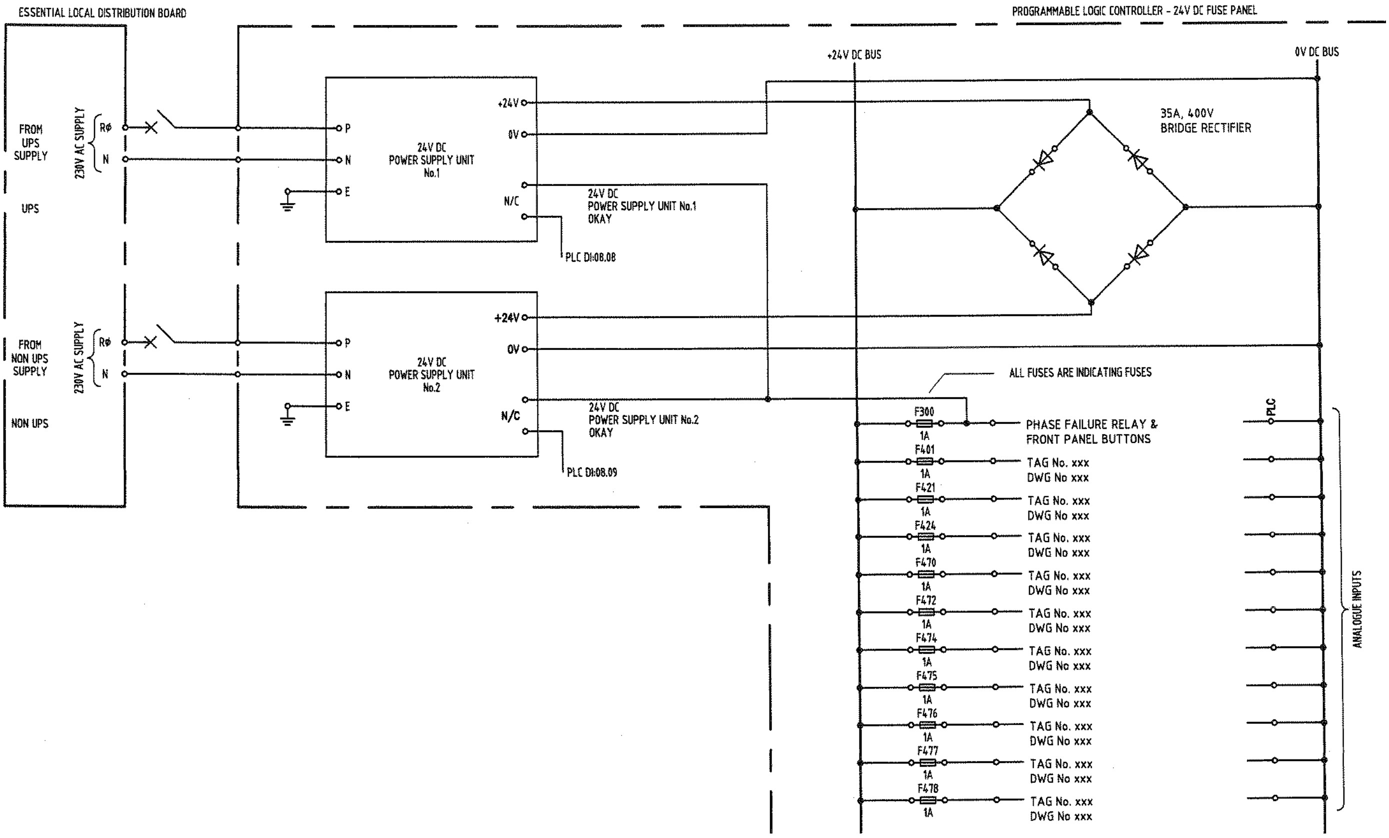
This authority has undertaken to provide back-up power for the four pump stations, which indicates the importance they attach to maintaining those facilities 24/7.

5 24 VOLT DC POWER SUPPLIES

There is a rise in the amount 24V dc supplies are used within a treatment plant. Two major reasons for this are: (1). It is highly compatible with an increasing range of instrumentation involving semiconductors which prefer the low voltage, and (2) the safety aspect. It is much safer for to deal with 24V because of the far lower risk of electrocution. A certified electrician is not required to wire it, and a lesser degree of insulation is required. Care still needs to be taken to clearly distinguish between the 230 Vac and 24V dc systems.

Because of this use of 24V dc for plant control and monitoring, many plants would stop completely if the 24 V supply failed. We have noted some very large, highly automated WWTPs which have only one 24 V dc source. It would be a near impossible job to then try and run the plant manually if the 24V supply failed. This risk could perhaps be reduced if a spare low voltage power supply was kept on site.

Figure 2: Generic Dual redundant 24 V dc supply system diagram



NOTES :

1. ALL CIRCUIT DIAGRAMS ARE DRAWN ON THE BASIS THAT THE ASSOCIATED PLANT AND EQUIPMENT IS IN A 'DE-ENERGISED' CONDITION, i.e. NO VOLTAGE, NO PRESSURE, NO FLOW, STOPPED, EMPTY, CLOSED (VALVES, GATES, etc.), OPEN (CIRCUIT BREAKERS, DISCONNECTORS, EARTHING SWITCHES, etc.)
2. ALL FUSE LINKS TO BE INDICATING TYPE FOR FAILURE WITH RED LED
3. EACH POWER SUPPLY UNIT IS RATED TO CARRY FULL RATED LOAD CURRENT
4. 230V AC SUPPLY IS A FILTERED SUPPLY AND SAME PHASE THROUGHOUT PLANT

Because of this hidden vulnerability, for any plant that must have a high ‘up-time’ that is, any municipal WWTP we would specify a dual redundant 24 V dc power supply. Each supply to have its own power source (CB) and diode isolation from the other at the 24 V dc busbar so that if one fails, the other will continue to provide the required 24V. This way, one power supply unit failure will not stop the plant operation. The faulty unit can safely be isolated from the mains (by its individual CB) removed and replaced without any ill effect on the plant. In addition, with this topology, because one unit <u>can</u> fail without affecting plant operation, the plant PLC is used to monitor the health of each power supply and generate an alarm if one fails. Where a plant incorporates a UPS, one power supply is fed from the UPS output and the other from un-maintained mains. That way it is also possible to run a separate ‘maintained’ bus for equipment such as flow meters or wet-well level sensors and telemetry for any items deemed important enough to continue monitoring during a power loss.

Example: A 24 V power supply failed in a large Auckland WWTP, on a Friday night. It was a dual system, the PLC picked up the loss and alerted us, and the plant kept running. It ran with just the remaining power supply until the Monday when it was replaced. This was done without any loss of plant operation. Had it been a single 24V supply system, a replacement 24 V power supply would have been required on the Friday night and an electrician / technician able and willing to come and replace it after hours or manual operation of the plant would have been required over the weekend. With this plant, manual operation was, at least, possible, though probably not to the same discharge standard, and it would be very labour intensive.

6 SIGNAL SURGE PROTECTION

The value of putting surge protection on signal lines coming in to the PLC requires consideration and a reasonable balance between the cost and the margin of additional protection provided.

Protection for digital PLC inputs is less important because they are pretty rugged. Although inconvenient, it is relatively simple to re-wire a digital input to a new terminal address and change the PLC code to match. PLC digital inputs are also relatively cheap and usually plentiful.

However the case for analog inputs is different.

Firstly, PLC analog inputs tend to be much more expensive and there are usually fewer of them to spare.

Secondly analog inputs can be 'wounded' without actually dying. They may be damaged by a surge input, where the analog input still works, but is out of calibration. The reason for the damage is usually that the PLC analog module input termination resistor has been 'cooked' or 'partially cooked'. The analog input relies on the accuracy of this resistor for the overall channel accuracy. If the terminating resistor is a different resistance than what it is supposed to be, the analog value converted to digital will also be inaccurate to the same degree. When a large amount of current passes through this resistor (from a surge) the resistor heats up. If it heats beyond the design temperature, damage can be expected in the form of a change in resistance. A slightly-out of calibration analog input is worse than a severely out of calibration one, as the error may go unnoticed but may still affect the process or results, whereas a severely out of calibration analog input is usually easily spotted.

Even surge protection will not always prevent damage:

Example: In a large food-waste to energy plant in Sydney, we had an electrical contractor with electricians who were unfamiliar with "loop powered sensors". These sensors only need 2 wires; these serving as both power supply and signal wires at the same time. Most are fed from a 24 V dc power source, and the loop powered device then 'modulates" the amount of current that passes through it according to the quantity it is measuring. This current is internationally standardised as lying between 4 and 20 milli Amps. The first 4 mA are used to run the internal electronics, the rest is varied by the device according to the quantity they are measuring. For instance, it may be a pressure sensor, purchased and calibrated so that 4mA = 0 pressure (0%) and 1 bar = 20mA or 100%.

This is a good, simple, widely used and robust system. However, electricians unfamiliar with it have a penchant for shorting the 24V supply wire directly to the 4-20mA signal wire when installing and commissioning such devices. For a non-surge protected, PLC, analog input, the result is certain failure. Even with good surge protection, survival from this sort of abuse is not guaranteed, but the damage has a better chance of being limited. Some PLCs build in protection to the analog input module itself, many don't. In the case of the waste-to-energy project mentioned, we lost 9 analog inputs due to the 'electrician' effect, from a total of 32 analog assignments in this one switchboard PLC control section. Three new modules were required to repair the damage.

The "electrician" effect can be reduced only by close supervision and careful testing at commissioning time. However, lightning and other transient electrical impulses are usually preventable by surge protection on analog inputs. A 3 stage unit, with a final clamp voltage of 33V dc and all units preceded by a 100mA fuse. are quite effective at preventing analog input damage caused by such transients.

In assessing which inputs to protect consider

1 The importance of the sensor information to the plant operation or client

2 The physical placement of the field sensor

3 Likelihood of transients

4 Client preference

Photograph 1: The Khorat waste to energy plant looking across the CIGAR flexible gas retaining cover. The plant control is in the buildings just beyond the cover to the left. The three 1.3 MW generator exhaust silencers can be seen on top of the square generator building. The rear-most, tall building is part of the factory being supplied the biogas for its boilers approx 0.8 Km away

Example: In Thailand a very large food waste to energy plant of Covered In Ground Anaerobic Reactor (CIGAR) design which produced biogas which is used for boiler fuel replacement (4MW equivalent) and electricity generation (3.6 MW). It was the first of its kind in Thailand, and they elected not to include any PLC analog input protection on the plant.

Some time after commissioning the plant stopped, and would not restart. A maintenance person had arc welded on one of the overhead, steel, cable gantries, and induced current had passed in to the analog inputs of the PLC, destroying the input modules and the controlling microprocessor. This took 3 days to repair, replace and reprogram. The plant was selling the energy (biogas) at US$6,500 per day; so nearly US$20,000 was lost. The cost of surge protection was less than US$1,000.

Surge protection may not have stopped this loss, but in subsequent plants for this client, surge protection was included, and there have been no similar issues.

7 ELECTRICAL HAZARDOUS AREAS

Any area where flammable gases and air are present presents the possibility of an explosion. Such an area is therefore an electrical hazardous area and the geographical and zone ratings surrounding this area are defined by international standards.

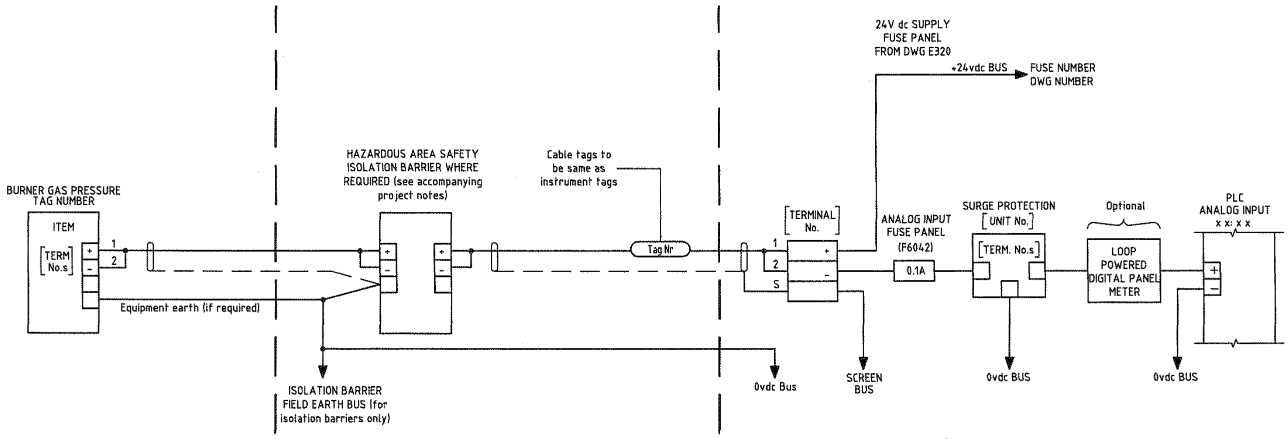
This applies not only to systems where we deliberately produce biogas, but also to places with the potential to produce biogas such as sewage sumps. These may produce biogas which then has the potential to cause explosion or fire if air and ignition source are not kept adequately separated.

For this reason, any plant that stores waste organic material, especially where air cannot continuously contact it (thus favouring anaerobic conditions), should be considered as being able to produce biogas and the electrical hazardous area standards should be applied.

Such areas, at least in WWTPs and pumping stations are usually fairly minimal, and usually easily addressed using adequate ventilation and standard hazard zone techniques, as well as by minimizing the amount of electrical equipment in the zone previously surveyed as being electrically hazardous.

The same cannot be said for biogas generating plants, as the production of flammable gas is the main object of such plants. The best way to minimize hazardous area difficulties is to carefully separate the gas components from other electrical components such as pumps etc. Where electrical equipment in hazardous areas cannot be avoided, use appropriate mitigating equipment to allow electrical operation in such areas. The general approach is to use electrical barriers between field equipment and the rest of the plant electrics to reduce the amount of energy that is available at the field device within the hazardous area to below the electrical energy required to ignite any gas – air mixture that may be present.

Figure 3: Typical Generic Hazardous area electrical diagram for a loop powered sensor in a hazardous area.



Where the amount of energy cannot be reduced to below ignition level, these items must either be mounted outside the area where gas is present, or use Ex or flameproof motors. These are designed and built so any gas that ignites inside the motor can readily escape before exploding the motor, but only by passing through specially engineered metal gaps of sufficient designed to cool the burning gases to below ignition temperature as they escape out of the motor. This is a similar principle to the Davy coal mining lamp, which though it had a flame inside, would not ignite a gas mixture outside due to the gas cooling effect of the metal gauze surrounding the luminous area.

8 HYDROGEN SULPHIDE

The nature of anaerobic bacteria means that along with any biogas produced, there will be traces of hydrogen sulphide. This gas varies within the range 200 to 5000 parts per million (ppm) of biogas produced. This gas is highly toxic down to 50ppm, and tends to accumulate in lower areas of pits, pipes etc. The tragic deaths of 3 workers in Auckland recently while trying to rescue other workers from an area unknowingly laden with H2S shows how careful we must be when doing any work associated with organic wastes, not to mention the likely depletion of oxygen in such places.

The other effect of H2S may not be so well known, and that is corrosion. H2S has a great affinity for copper, silver and any alloys containing these, such as brass (taps and fittings), bronze, phosphor bronze (used in switch and relay contact spring assemblies) beryllium copper (contacts) and so many others. Many will have seen the black coating that develops on brass taps around WWTPs. This is usually from the H2S present, even when it is in very small quantities.

H2S forms a flaky, black, non-conductive coating on copper wire, buss bars etc and is particularly troublesome with the very fine copper wires used for instrumentation.

Many manufacturers advertise their Variable Frequency Drives (VFD) / Soft Starters (SS) / DO meter etc, as having "conformal coating" on the internal printed circuit boards (PCB). This indeed seems to reduce H2S attack, but does nothing for other areas which are still part of the circuit. This would include areas at the edge of a printed circuit board which are intended to plug in to a socket for instance. These are often left exposed unless plated with a less reactive metal such as gold, but then the gold must cover all the copper parts not covered by conformal coating.

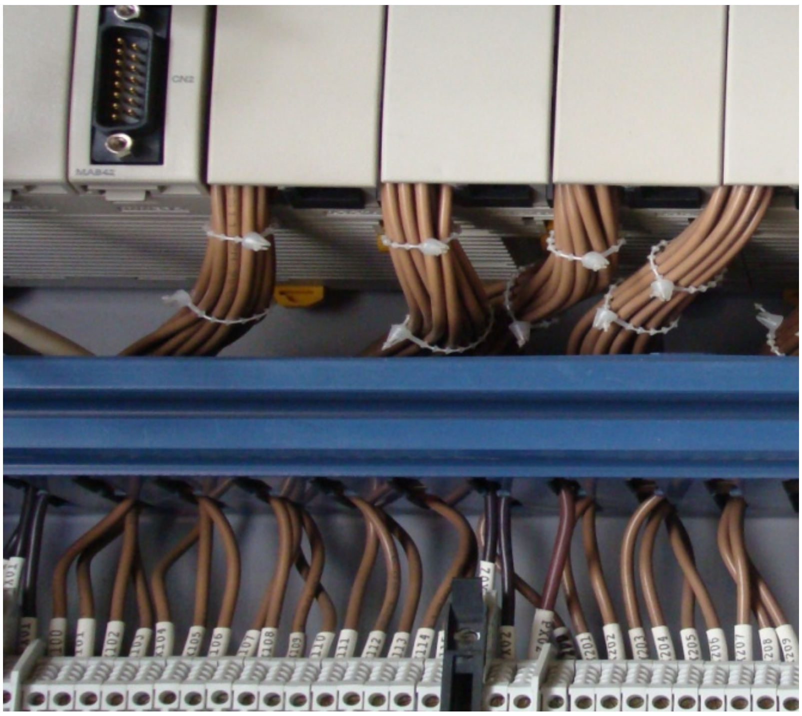
Example: The Waste Solutions division of CPG designed built, tested and shipped a containerized pilot plant to the Philippines for use in waste-to-energy trials of distillery waste. These pilot plants contain all the electrical equipment a full sized plant would have except that the motor sizes are scaled down. Nevertheless, all test and sensing equipment is the same, including the Human Machine Interface (HMI) used to control and monitor the plant.

Photograph 2: H2S corrosion from WWTP plant. a, untarnished copper, b, corroded copper, c, silver contacts badly blackened

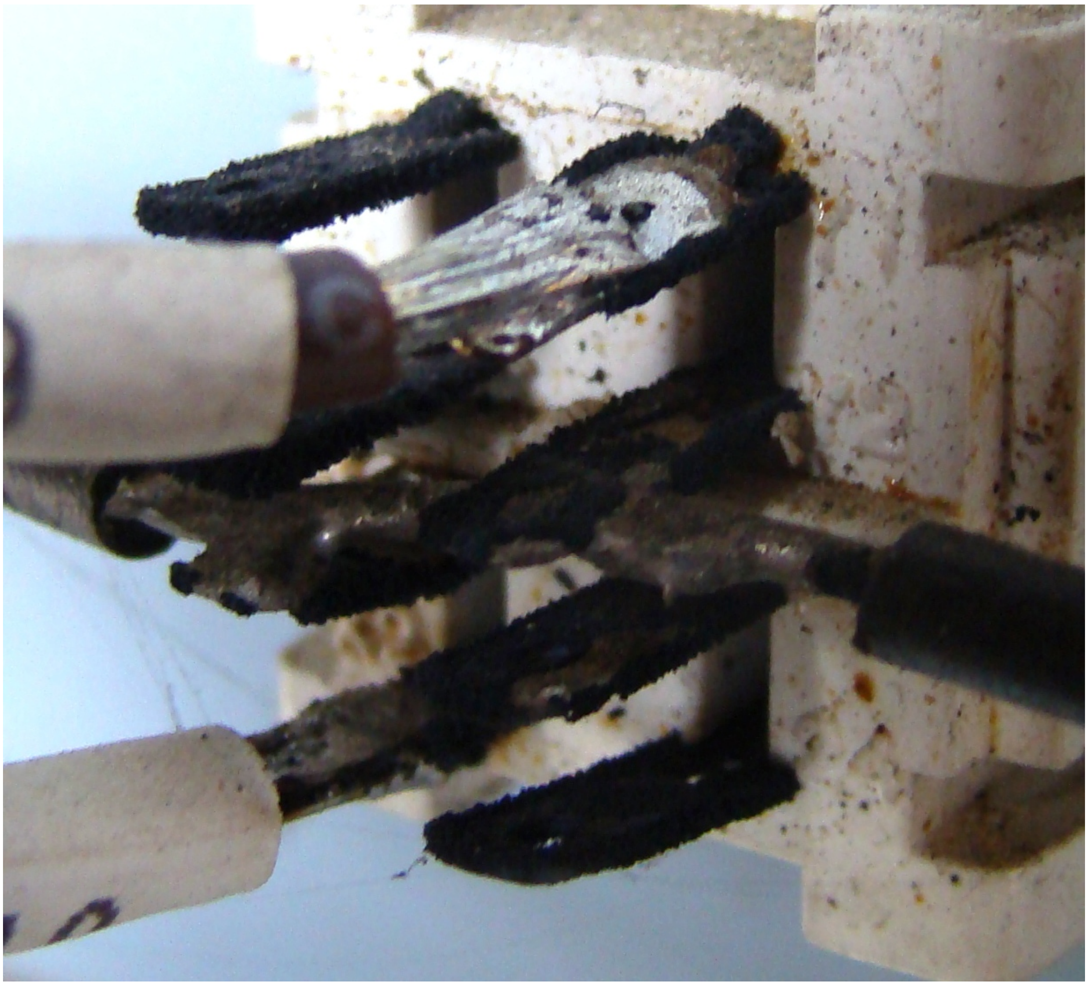
a *b* *c*

Photograph 3: Electrical section of Pilippines containerised pilot plant – Reactors and powered ventilation to the left

Photograph 4: Flow meter on right saved from attack by good sealing and cable glands



Photograph 5: Those wires should be mostly white! The colour has been changed by the H2S in the area



Photograph 6: Severe H2S damage to switch terminals. Note area of solder (silver) untouched by H2S

The waste was high in sulphur content, which usually also means high H2S from the biogas, so two extractor fans were added, one for general container air and one specifically over the reactor to remove any H2S before it could escape and become a problem.

However the reactors were seeded with anaerobic bacteria, then the plant switched off and mains power removed for a period of a month before reactivation. This switch-off was a by-product of political instability in the area at the time.

The bacteria continued, albeit slowly, to evolve biogas, with H2S, which then had no way of escaping from the container it was built in; and the doors had been securely closed for protection!

When pilot studies were restarted, the reactor ventilation fan failed, followed shortly by a defective power meter.

Studying the evidence supplied from the Philippines site, we concluded that the local power supply must have had too high a voltage. This was declared unlikely, but was the best explanation we had at the time.

These failures were soon followed by other reports; that the HMI was not working properly, then the UPS failed, followed by the VFDs and finally the PLC itself. The only items that seemed to escape were the Yokogawa flow meters and the pumps.

By this time it was obvious the problem was nothing to do with local mains voltages or surges. The clue was the flow meters, which were IP65 rated, and therefore much better sealed against the local atmosphere. This was one of the few places the H2S could not penetrate. In all, NZ$10K worth of gear was lost due to H2S damage to electrical equipment on this project in the space of 3 months.

H2S damage is non reversible, and cumulative. As long as there is any H2S about, the damage will continue to get worse, and there is nothing that can be done to repair it other than by replacement of affected parts.

Our mitigation measures are:

1. Group as much of the likely affected equipment in one place as possible.

2. Reduce the air exchanges as much as possible in the area containing electronic / electrical equipment.

3. Install H2S absorbing / neutralizing material inside the equipment air-space.

4. Seal up any field equipment to exclude ambient air

5. Minimise electrical field cabinets

This is achieved by designating a switch / control room, and mounting most of the electrical and control equipment in that one room.

The whole room to be semi sealed, and then use air conditioners to keep the temperature reasonable for equipment. This room is usually mounted inside, or adjacent to another 'control' room. There are then two doors between the electrical gear and the outside to minimize air exchanges.

VFDs and SS are the biggest heat generators, and these require a separate cooling air circuit direct from outside, over the high powered semiconductor heatsinks, and back outside, with no mixing of the air within the electronic section. This minimizes the burden on the air conditioning system and will allow longer operation before over temperature shutdown in the event of air-con failure.

Glass doors are used in to this area of the control building. This allows personnel to view the switchboard without having to enter the room. A separate HMI PC is usually mounted outside this room to allow plant status and control. Two PCs allow for redundancy.

Photograph 7: Switchboard behind glass to allow observation with minimal need for personnel entry to reduce air exchanges

H_2S sacrificial absorbing material can be placed in the control boards, together with rubber sealing lips on the cabinet doors.

Junction boxes on the field are sealed once commissioning is completed and absorbing material installed. However, we minimize field junction boxes as much as possible, preferring to run cables directly between field devices and the control / switchboard.

9 TRICKS OF THE TRADE

- Group controls in one area as this makes it much easier for operators to assess plant status in one place. Controls scattered all over a switchboard invite forgetfulness or lack of notice. Group associated functions to improve ergonomics.
- Manual-Off-Auto (MOA) switches allow plant operation to continue when the PLC dies.
- Include panel meters in the control section for flows and levels that may otherwise be hard to see, so vital functions can still be read if the PLC / SCADA fails.
- Feed all mains powered control and sensors off the same mains phase throughout the plant. This helps to eliminate cross-phase interference on analog signals.

10 CONCLUSIONS

While it is not possible to give more than a brief glimpse of the lessons learnt, it is hoped that those presented will alert others charged with designing facilities to details they may not previously have considered during plant design.

ACKNOWLEDGEMENTS

Thanks to Switchbuild for several of their corrosion damage photos.