UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT AND APPLICATION OF DESIGN AND INSTALLATION CHECKLIST FOR GULLY-DRAIN IN A MEAT PROCESSING FACTORY BASED ON HYDRAULIC AND HYGIENIC ANALYSIS

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186888

A PROJECT REPORT SUBMITTED IN PARTIALLY FULFILLMENT OF THE REQUIREMENT FOR THE

BACHELOR OF PROCESS AND FOOD ENGINEERING

DEPARTMENT OF PROCESS AND FOOD ENGINEERING

FACULTY OF ENGINEEERING

UNIVERSITI PUTRA MALAYSIA

2020

ACKNOWLEDGEMENT

I am grateful I have been given health, strength and determination by the God to complete this final year project. Special thanks to both of my parents and family who had been my backbone and true supporter since the beginning of my studies until now and then.

I also would like to express my gratitude to Dr. Noor Zafira Noor Hasnan, who has helped, supported and closely consulted me throughout the research and thesis writing and for giving me so much patience, guidance. Dr. Noor Zafira Noor Hasnan, the project supervisor, always offered me some helpful advice and cares for me. Thank you for your trust on me to work on this project and allowed me to learn the real scenario in the food industry. With her support, I am only able to complete this project. I would like to apologize for any imperfection in completing this project.

I would also like to express my precious thanks to the owner and staffs of the Factory Y who had given me full cooperation throughout my research. Moreover, thanks to my examiners, lecturers and staffs in the Department of Process and Food Engineering for your kind assistance and endless guidance. Last but not least, big thanks to my course mates for the sharing of information and advice. It such a blessed to have all of you in my study life.

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ABSTRACT

Floor drainage is an integral part in food processing facility which directs surface wastewater from production environment to sewage system In Malaysia, most small enterprises have some issue in hygiene and drainability aspects, since they were designed and installed by the non-specialist contractor for food processing. Hence, this project was performed to analyse the occurrence of contamination and flooding due to errors in design and installation of the gully in a burger meat patty producer, Factory Y.It was found that as production time progressed, level of flooding increase with number of clogged holes of Drain Y was observed due to the size of meet remnants with average length ≥ 2 cm that flowed with the wastewater into the grating holes of diameter, ⌀ =1 cm. In addition, the measured ATP reading was highest for drain edge (10846 RLU/100cm^2) followed by perforated holes(5484 RLU/100cm^2) and grating surface (3793RLU/100cm^2) which do not meet the benchmark for food industry The swab test results showed that the alarming presence of microbes which includes aerobic plate count (APC), *Listeria spp.* and *Escherichia coli.* The aerobic plate count is the highest which is 5.3×10^6 CFU/ cm^2 in drain edge, followed by 4.5×10^6 CFU/ cm^2 in perforated holes, 2.4×10^6 CFU/ cm^2 in grating surface and 8.1×10^4 CFU/ cm^2 in the soil water inside the drain. Lastly, a new design and installation checklist was developed for gully-type floor drain in a meat processing factory (wet production) that can be utilized by small-scale premises when setting up the factory and demonstrated in a new designed model for Factory Y. The current drain at Factory Y has 2 out of 12 criteria for drain 2 at factory Y are met (16.67%) for its design, and 3/11 criteria are met (27.27%) for its installation.It is hope that the insights provided by the study could raise the awareness of the risk caused by inefficient and unhygienic drain on the overall food company's performance

ABSTRAK

Sistem saliran merupakan satu komponen yang kritikal dalam sesuatu kiliang pemprosesan makanan untuk mengeluarkan air kotoran ke sistem kumbahan.Namun,kebanyakan kilang mempunyai masalah dalam aspek kebersihan dan kapaciti hydraulik, kerana ia dirancang dan dipasang oleh kontraktor bukan pakar. Oleh itu, projek ini dilakukan untuk menganalisis kesan reka bentuk dan pemasangan saluran terhadap kebersihan dan kapaciti saluran di kilang Y yang menghadapi masalah tersebut. Melalui analisis, didapati lubang sistem saluran menambah apabila air taip tidak ditutup. Ketinggian kebanjiran meningkat dengan semakin banyak lubang yang tersumbat Di samping itu, bacaan ATP yang diukur adalah yang tertinggi untuk pinggir longkang (10846 RLU / 100cm2) diikuti oleh lubang (5484 RLU / 100cm2), permukaan parut (3793RLU / 100cm2) yang tidak memuaskan.Hasil ujian swab menunjukkan bahawa kehadiran mikroba yang membimbangkan Bacaan plat aerobik adalah yang tertinggi iaitu 5.3×10^6 CFU / cm2 di tepi longkang, diikuti oleh 4.5×10^6 CFU / cm2 di lubang berlubang, 2.4×10^6 CFU / cm2 di permukaan parut dan 8.1×10^4 CFU / cm2 di air tanah di dalam longkang.Akhir sekali, senarai semak dari aspek reka bentuk dan pemasangan baru diwujudkan untuk longkang lantai jenis gully di kilang memproses daging basah yang memanfaatkan premis berskala kecil. Saliran semasa di Kilang Y dapat (16.67%) untuk reka bentuk dan (27.27%) untuk pemasangannya. Saluran yang baharu juga ditunjukkan berdasarkan senarai semak untuk Kilang Y. Diharapkan bahawa pandangan yang diberikan oleh kajian ini dapat meningkatkan kesedaran akan risiko yang disebabkan oleh sistem saluran yang tidak cekap dalam pemprosesan makanan.

CHAPTER 1

INTRODUCTION

1.1 Overview

Floor drainage system is an integral parts in the food processing plant which directs wastewater from inside production facilities to the sewage system for wastewater treatment. Floor drainage is a critical component which affects the hygienic and operational performance of food production facilities, by intersecting, conveying fluid from various sources, and serve as a barrier for protection. Operationally, the floor drainage helps to prevent the pooling of water especially in wet processing area, which in turns protect operators from slippery risk. Meanwhile hygienically, it is required by Food Hygiene Regulations 2009 Section 29 that floor drainage should be adequately designed and constructed to avoid any risk of contamination to food in a food premise.

There are different types of drains such as trench drain (channel), point drain (gully) and slot drain. Different drains have their specification. A proper and well-suited drain is important to ensure its functionality in removing wastewater and to maintain the hygiene of food processing. The importance of well-designed and installed floor drain is pronounced for meat processing, as the water consumption for meat processing industry ranges from 5.7-12.7 kL/tonnes meat. (Meat Processor Corporation, 2017). About 90% of freshwater intake in a meat processing plant will become wastewater (Baker, 2013). Additionally, wastewater produced from meat processing is difficult to treat due to its high total suspended solid contents, high oil and grease concentration, high temperature and biochemical oxygen demand (Kiepper, 2003). This amount of wastewater is critical to be removed effectively through the internal drainage system to prevent slippery injuries and potential microbial adhesion (Fairley et al., 2014).

Poor floor drain's design and installation lead to ineffective removal of wastewater and also compromised hygiene. According to Myers et al. (2018), highest non-fatal injuries arise in the food industry are slips, trips and fall (STFs) in which some are due to ineffective removal of wastewater on the floor. In particular, there have been linked on STFs with the onset of low-back disorders, which, can leave the worker physically limited both in the workplace and at home (Kathawala et al., 2018). Meanwhile, based on the hygiene point of view, many drains have tested positive for undesirable microorganisms particularly *Listeria* in meat processing plant. In fact, a 2004 audit of food processing facilities in a Midwestern state by the United States Department of Agriculture's Food Safety and Inspection Service reported that 27.8% of floors and drains sampled tested positive for Listeria (Makdesi, 2010). This problem has left food processors puzzled and searching for an effective drain cleaning program. *Listeria monocytogenes* is a type of bacteria that causes serious infection known as Listeriosis (Fairley et al. 2014). Listeriosis can cause severe illness, including severe sepsis, meningitis, or encephalitis, sometimes resulting in lifelong harm and even death. Noting that the floor drain is a receptor of fluids from processes, cleaning or accidental spills, hence it is not surprising that drain components harbor bacteria. Some studies highlight the drain as the most significant environment site for microorganisms including *Salmonella* spp. in pig slaughter houses and *Listeria* spp. in meat, dairy and smoked fish processing plant (Parisi et al., 2013; Rotariu et al. 2013).

Against the above background on the importance of well-designed and-installed floor drain, it can be concluded that there are multiple factors need to be considered during the selection, design and installation of the drains, such as the cleanability, maintenance cost, traffic, location of installation, floor-to-drain connection and types of materials used for the construction of the drain. The motivation of the studies is to investigate the impact of ineffective design and installation of internal floor drainage at a meat processing factory on the hygiene and its efficiency in removing waste water from the floor.

1.2 Problem statement

Components of floor drainage in the food industry are often fabricated by non-drainage-specialist companies. In the European Union (EU), it is estimated that more than 200 contractors fabricate and install drainage components, whereby the majority are often fabrication companies with no specific expertise in drainage (ACO, 2019). Thus, there is huge inconsistencies in how floor drains are fabricated and installed on-site. As a result, improper drainage system is built within the premises which does not meet the operational and hygienic requirement of the food processing plant. In Malaysia, the same challenge is reported by Jali et al. (2016), whereby the cost for hiring specialist consultant and contractor is not affordable by small-scale food manufacturers and hence, a well-functioning floor drainage systems are difficult to fabricate and rarely obtained. Ready-made food-grade drainage components can be purchased from the market, all of them are foreign products which have to be imported and are costly for local manufacturers.

In this case study, Factory Y, is an example of a meat processing factory that faces drainage problem, which was due to faultiness in design and installation. The current drainage, which is of gully-type drain, was not correctly designed according to production characteristic, wastewater flow volume and flow rate. The gully is poorly located and the design has overlooked the linkage with flooring and cleaning activity. Hence, the factory faces issues with pooling of wastewater during production, too-wet flooring and ineffective cleaning for the gully, which violates the Food Hygiene Regulations 2009. The pooling of wastewater in certain location risks workers to slip and fall. In fact, during the audit for the certification of MeSTI and Good Veterinary Hygiene Practice (GVHP), the wet floor surface was always identified as non-conformance finding that needs to be corrected. The retrofit for the gully is however too expensive to be done and would disturb the production activities.

Nonetheless, even with better design, one still can expect minor problems related to drainability as well as hygiene when it is implemented in food factories due to the varied characteristics of food production. Thus, the study seeks the importance of investigating the degree of seriousness in problems related to floor drainage in a meat processing facility caused by faultiness in design and installation. Consequently, the study proposes a guide for the fabrication and installation of the floor drain for the gully-type.

1.3 Objectives

The project aims to propose a suitable design and installation checklist for gully-type drain in meat processing based on hydraulic and hygienic analysis.

The specific objectives are:

1. To evaluate the effect of design and installation of gully drain on hydraulic and hygienic efficiency in an identified case study factory

2. To propose design and installation checklists for gully-drain in meat processing based on hydraulic and hygiene analysis in an identified case study factory

3. To test the applicability of the checklist in redesigning a new efficient and hygienic gully-drain for the case study

1.4 Scope of work

Upon completion of this research, a detailed understanding of the effect and role of floor drainage's design and installation on two aspects are obtained, namely 1) hydraulic efficiency and 2) hygiene efficiency in a meat processing factory.Specifically, the study was carried out in a wet area of a meat processing plant, Factory Y located in Kajang. In our case study, I will inspect the drain model in Factory Y which is a producer of burger meat patties which generates large amount of wastewater daily. The waste water produced contain large amount of perishable meat waste particulate which can clog the drain holes. The factors that is responsible for the hydraulic performance of the drain can be relate to its area of opening, sloping and location. While surface roughness, minimum radius of corner, availability of minimum hygienic accesorries affects the drain's hygienic performance directly. The hydraulic efficiency at drain inlet of the specific drain model in our case study factory, was calculated and discussed in related to its changing hydraulic capacity of the drain during production. Meanwhile, the hygienic performance of the specific drain in case study factory was discussed based on ATP bioluminescence assay and microbial contamination swab test results, where the samples are taken from grating surface, drain edge, perforated holes and accumulated soil water underside of the gully in the factory according to the food factory benchmark The study was concluded with the development of general design and installation checklist for the gully (point drain) in a wet processing area for meat products. The checlist is illustrated by drawing a new gully drain that is suitable for the replacement of the current drain model in Factory Y to address their operational and hygiene issue.

1.5 Thesis structure

This thesis consists of 5 chapters which describe this research in detail. Chapter 1 generally introduces the internal drainage in the food industry, the problem faced by the food industry and research objective. Chapter 2 contains the literature review through an online database, journals and books. Chapter 3 summarizes the methodology performed for this research project. Chapter 4 contains all results and discussion obtained from the investigation. Chapter 5, the final chapter provides the general conclusion on the research followed by acknowledgement.

CHAPTER 2

LITERATURE REVIEW

2.1 Floor drainage and its types

In food factories, the primary function of floor drain in a food factory is to remove the waste water for a given period of time particularly in wet processing area. The waste water may be the fluid from cleaning process, specific equipment discharges or accidental spills. Drainage converges all the streams together, collects the surface water and drains them away to the sewage and separate the production area from the sewage system. It is a critical component that affect the hygienic performance of food production facilities while intercepting and conveying fluids from a variety of sources whilst providing a barrier function used to segregate areas and separate the internal environment from the sewer and prevent invasion of pest such as rat, cockroach. Proper planning is required and need to consider factors such as location for installation, wastewater characteristics and temperature, types of detergent used and the location before installation of the drainage (Fairley, Smith, & Timmerman, 2014).

This study has its focus on the gully, one type of floor drain as can be seen in Figure 2.1.1. Its main function is to sediment sources, store and transfer the flow from the floor with slope downstream to the drainage piping. The gully consists of removable grating, foul/odor air trap, foul air trap support, channel body, optional filter basket, earthling, leveling feet and outlet cover (Blucher, 2011). The bottle gully accepts waste discharged from equipment or cleaning water jet. The function of the grating is to block the passage of large particulate from flowing into the drainage. The foul air trap serves as a barrier between the production area and sewage system. Without the foul air trap, the foul air will escape to the environment, which carrying the microorganism to the food and will eventually compromise the food safety. Drain pipe helps to convey the waste water to the sewage system. Filter basket can reduce production downtime by the need to empty the clogged filter basket. Gullies are height adjustable for ease of installation. Outlets can be vertical or horizontal.

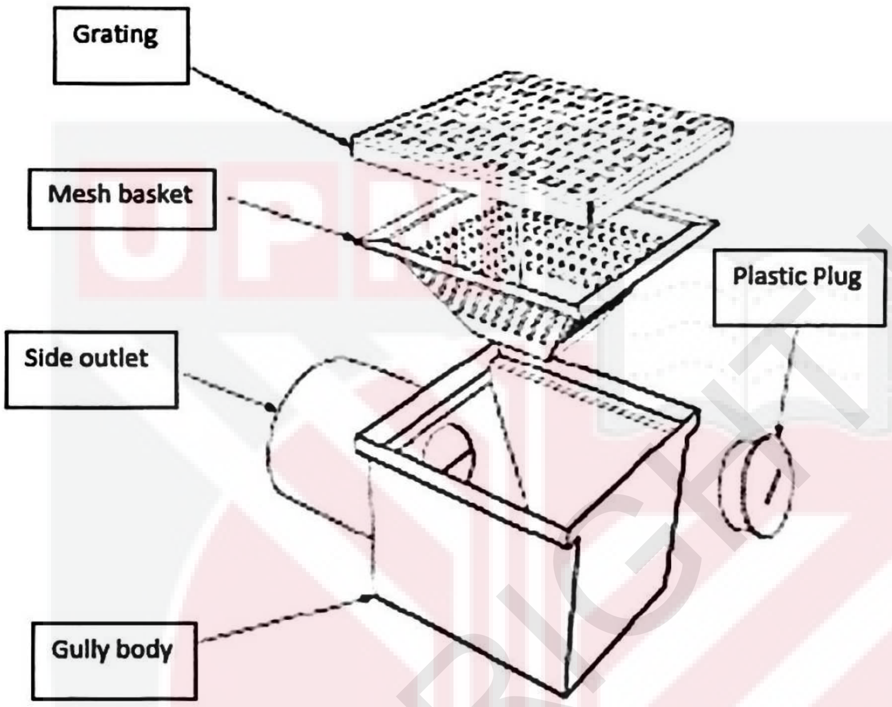


Figure 2.1 1: Gully structure

Channel type drain is installed for a greater coverage production area. Especially when the specific process consume and produce large amount of waste water, channel type drain would be a preffered choice for example in a large scale meat processing factory such as Nutriplus factory. Channel drain or trench drain have better hydraulic capacity compared to gully drain because they drain water along the entire length of the flooring. Most of them functions based on the natural sloping and gravity. In terms of its structure, channel drain consists of an enclosed channel with a grating above it.

2.2 Legal and standard requirement

Construction of drainage inside the factory should follow the laws and regulation. The Street, Drainage and Building Act 1974 which controls the drainage specification of a premises.

The law stipulates that the waste effluent should not communicate with river, canal, stream, pond, lake, sea without the prior written permission of the local authority. Any person who contrary to it, is liable on conviction to a fine not exceeding one thousand ringgits. Besides, the plant drainage should be built at an area which has sufficient water supply and sewer for efficient flushing and cleaning and efficient removal of animals or vegetables matters. Besides that, the owner of the premises should ensure that the drainage have sufficient closet, sink in the building(The Commissioner of Law, 2007).

When drainage is installed in a food factory, another regulations become substantial which is the Food Hygiene Regulations 2009. Regulation 13 has stated that the design inside the food factory should facilitate cleaning and disinfection which also include floor drainage. Regulation 29 is about the drainage facility should be adequate, smooth type material, fitted with food trap designed and constructed to avoid any risk of contamination to food (Thangayah, 2009). Malaysian Standard MS 1514: 2012 Good Manufacturing Practice (GMP) For Food is a food standard that facilitates the process of meeting the requirements of Food Hygiene Regulations 2009 and Food Regulations 1985. In clause 4.6.2, drainage should be designed and constructed so that the risk of contaminating food or the potable water supply is avoided. In clause 6.3.3, facility shall be maintained in a sanitary condition and shall be kept in good repair. The drain should be able to perform its hydraulic and hygienic performance, in compliance with the one of the Halal guidelines which is to produce clean and healthy food in Malaysia.

2.3 Wastewater characteristics in meat processing

The site of the study is the meat processing facility generates large volume of wastewater produced daily. The wastewater generated generally carries with it slurry, meat remnants, blood, hair, pieces of entrails, and surface fat. Hence, the water has a content of organic matter, material in suspension, oils and fats, nitrogen (ammonia and organic), phosphates, and detergents and disinfectants used during cleaning (Wastewater treatment in meat industry, 2015). Nitrogen and phosphorus is present in meat processing waste water in several forms and are pollutants termed a "nutrient", since they are essential elements for life. They are largely derived from proteins dissolved into wastewater from meat tissue, blood (nitrogen), paunch liquid and stockyards. The nitrogen and phosphorus content from wastewater is under stringent control by Australia which the nitrogen limit is less than 50mg/L and phosphorus limit is less than 10mg/L (Meat Processor Corporation, 2017). While total chemical oxygen demand (TCOD) ranged from 2333 to 8627 mg/L and suspended solids (SS) varied between 736 and 2099 mg/L (Massé et., 2000). The industrial food waste from meat sector is 13,440,000 tons per year in year 2009. (USEPA, 2012).A poultry processing facility which processes 400,000 birds per day and generates 1.3 million gallons of wastewater (FRC, 2015). The wastewater also includes the wash down from equipment cleaning.According to National Water Quality Standards for Malaysia, the allowable limits for class I water to maintain water environment's cleanliness should not contain more than 0.1mg/L Nitrogen, 1 mg/L biochemical oxygen demand (BOD), 10 mg/L chemical oxygen demand (COD), 7mg/l dissolved oxygen (DO), 500mg/l total dissolved solid (TSS), 25mg/l total suspended solid. (DOE, 2019)

2.4 General gully's design and installation

Gully is a square drain design ranges from 100-400mm, and the hydraulic capacity can reach a value from 0.4-11 L/s (Fairlery et al., 2014). The location, number, size and open area of gully are important factors in the design. Besides, others factor such as the downstream pipe size, length and flow rate of the pipe need to be considered.

Location of installation is influenced by waste water direction, traffic, proximity to waste water source. If the gully is built at a far place from the source of discharge, the wastewater takes longer time to flow into the drain.

There are also 3 types of load bearing for drainage such as light, medium and heavy duty drain. Medium and heavy duty are designed for area with frequent traffic of trucks. Light duty is for frequent pedestrian traffic. In areas where pedestrian traffic is the norm, floor drains with heel-proof grates should be used with the holes size 0.7mm. Suitable type of drainage should be selected to resist the load applied on it. Besides, the drainage should be installed to allows the flow direction of the waste water is from high risk to low risk area. On the other hand, the drain should also fastened with frame to ensure stability. Last but not least, point gully should be installed at a location to receive falls from 4 sides and near to the fluid source.

The ope-area determines the inlet hydraulic capacity of the gully. If hydraulic capacity is smaller than hydraulic load produced from factory, it will cause flooding at the production area. Flooding could cause serious problems in terms of operational and hygiene problem. Hydraulic capacity is the flow rate of water that flows through the inlet drain structure. Insufficient hydraulic capacity will reduce the hydraulic efficiency of the drainage system. Equation 2.4.1 is used to calculate the hydraulic capacity of a floor drain is as below (Wood et al., 2010):

$$Q = C_d \times A \times \sqrt{2gh}$$

Where, Q = Hydraulic capacity, C_d = Discharge coefficient (0.6), A = Cross sectional area ,h = Allowable height of flooding = max. head above floor.According to the equation of hydraulic capacity as shown in equation below, minimum total open area of an optimum drainage system depends on the two factors which are 1) hydraulic capacity required for a specific drain, 2) maximum allowable head in the concerned area (maximum allowable flooding level).

While the maximum allowable flood height,h is 20mm (Holah, & Lelieveld, 2016). But through our observation we tend to set it at 5mm as we discovered that head above 10mm will make walking difficult. If hydraulic capacity is smaller than hydraulic load produced from factory, it will cause flooding at the production area. Flooding could cause serious problems in terms of operational and hygiene problem. In the context of safety of workers, flooding cause accidents such as falls down due to slippery surface. On the other hand, food may be contaminated due to the bio-aerosols from the drain, where the microorganism migrate from the pool of flood to the food. Wastewater from the flood will splashed to the travelling trolley of raw materials or finished products.

2.5 Hygienic drain design

In food processing environment, drain components can be considered 'environmental surfaces' – with no direct food contact but with clear potential to act as a source of contamination (Fairley et al., 2014). Generally, issues related to the component design give rise to hygienic concern. Hygienic design of drainage includes continuous welding of joints, radiused corners and drainability (ACO, n.d.). The water trap used should be removable, can be separated for cleaning, improve water flow as compared to other traps. Drainage design will affect in-situ hygienic performances, poor drainage design might further facilitate initial microbial adhesion, promote localized sedimentation or settling of lipids. In fact in 2019, according to white paper by ACO Building drainage, 70% of positive listeria screens are found in drainage and floor environment in food and drink factories which can cross-contaminate the food nearby as in Figure 2.5.1 (ACO, 2019).

Figure 2.5 1: Possible cross-contamination due to bio aerosol occurrence from drainage

Figure 2.5.2 and Figure 2.5.3 shows a comparison of a good and poor gullies design for hygienic design. (Frank & Patrick, 2015). The following details indicate the hygienic design of floor drain:

- The edge in-fill is the filling of materials such as resin at the space between the flooring and drain. This can prevent the build-up of microorganisms.
- The radiused corner has higher cleanability compared to the sharp corner. A sharp corner will form a dead space the brush can't access to.
- The joint of the drainage is welded instead of metal-to-metal contact to increase the stability and shelf life of the stainless steel materials.
- The water trap should be removable for easy access for cleaning. The fixed water trap is more difficult to clean as biofilm may develop on the surface of the water trap as it always contains a water surface to absorb the foul smell backflow from the sewage.
- Drainage should have a drainable body to avoid the accumulation of water. The drainable body allow us to remove the solid residue from the drainage system from time to time.
- Surface of the drainage is smooth to improve the hydraulic performance of the drainage. The wastewater is greasy because of the food soil presents which will affect the

flowability over the drainage. The EHEDG recommends average surface roughness of < 0.8μm for food standard, though, values up to 3.2 μm would be acceptable as long as the cleaning fluid flow rate is sufficient enough to remove the soils from the surfaces (Milledge, 2010).

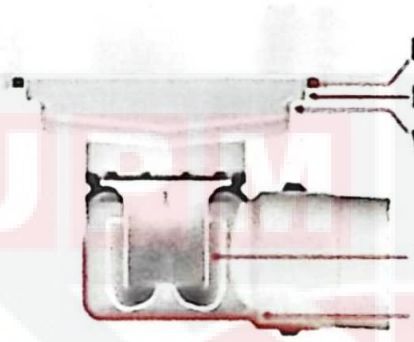


Figure 2.5 1: Hygienic design of gully(Frank & Patrick, 2015)

Figure 2.5 2: Poor design of gully (Frank & Patrick, 2015)

To carry out a dry cleaning, contact surfaces should be fully accessible for safe manual cleaning and inspection. In order to carry out a hygienic wet cleaning operation, contact surfaces should not be horizontal, but have a slight slope to facilitate drainability of cleaning solutions. (Collins & Huey, 2014).

2.6 Drainage installation for food factories

Installation of gully consists of 6 phases as given in Table 2.6.1. Adequate installation and maintenance are essential for the proper and lasting performance of drainage system (F.A.O., 2005).

Table 2.6 1: Installation of gully

Phase	Description
1	The outlet cover is removed and connect to a pipe. Ensure seal the pipe and outlet cover properly. If the gully outlet pipe is horizontal, make sure there is a minimum gradient of the pipe.
2	Level the gully at the required height and horizontal plane using the leveling feet.
3	Concrete the gully carefully up to the half-height of its body. Before placing the concrete over the entire floor, it is necessary to keep the technological break to ensure the curing of the concrete.
4	Complete the concreting to the required height. Consider the wear layer thickness of the completed floor.
5	Lay the final floor layerFill the gap around the gully top by a flexible sealant. Remove all the protective elements (blister or foil).
6	Install the foul air trap by pressing into the foul air trap support. Fill the foul air trap with water, and install the grating.

In term of installation, the floor-to-drain interface is a potential spot for accumulation of wastewater that provide harbourage space for pathogen when not properly sealed off as in Figure 2.6.1 .

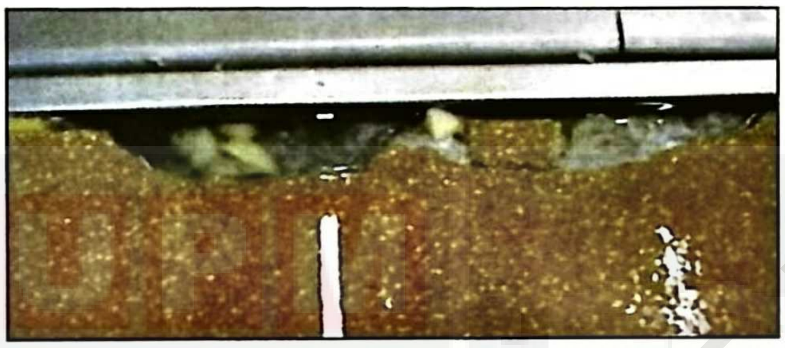


Figure 2.6 1 Poor floor-to-drain interface installation that can harbor microbial growth (EHEDG Doc 44, 2018)

2.7 Operational and hygienic issues related to the poor drainage

Operationally, insufficient hydraulic capacity will cause ineffective removal of wastewater. (Fairley et al., 2014). Improper drainage cause flooding of water, blood or grease which will cause falls. The wet conditions will pose a safety threat to the workers. Since slippery floors are a major cause of falls, protective clothing such as safety shoes or boots with toe guards and slip-resistant soles must be worn by workers. Slips, trips, and falls (STFs) represent one of the leading causes of occupational injuries and fatalities. Slippery can cause mild to severe injury to the workers if they hit their head. A result of analysis conducted by The European Commission on the non-fatal accidents at the workplace during 2015, slipping, stumbling and falling was the largest reported category, which constitutes 14.4%, which is 573,679 out of 3,983,881 cases. Another similar study conducted by US Bureau of Statistics (BLS) in 2014, 17.4% of the non-fatal occupational accidents and disease fell on the same level, while 4.4% of them were slip that does not cause falls (Kathawala, 2018). In case of slip or trip that does not falls down, it will cause low back injuries due to natural instinct of body's effort to regain balance. Slips and trips that do not lead to falling, also called "near-accidents," are known to be hazardous to the spine - potentially due to the rapid corrective movements made to restore balance. Researches also proves that 11% of back-pain related claims can be attributed to slips and falls. (Murphy & Courtney, 2000).

A review has been done on occupational injury and fatigue risk factors that the most common cause of fish harvester deaths in the Gulf of Mexico Seafood Harvester is falls overboard with insufficient floating devices due to flooding and slippery surface of the deck (Myers, Durborow & Kane, 2018). The 2010 study also determined the highest cause of fatal falls was "trips and slips" on the deck followed by "lost balance as shown in Figure 2.7.1. (Myers, Durborow & Kane, 2018). Hence, it proves that slippery surface is a hazardous risk in the working environment. Besides, fatigue will also increase the risk of injury of workers while working. The operators feel exhausted to sweep water from time to time. Most of the operators are multitasking all the time.

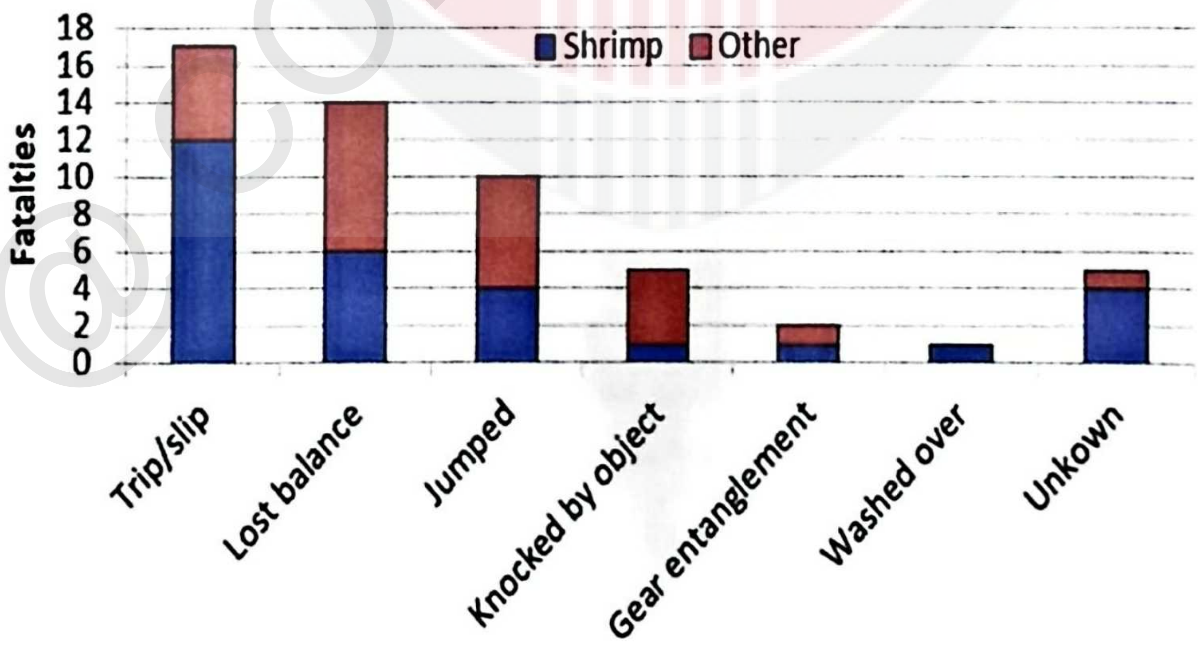


Figure 2.7 1: Cause of fatal falls overboard in food industries (Myers, Durborow & Kane, 2018)

Floor drain in food processing facilities play an important role for the persistence of listeriae and can be a point of contamination (Kouker & Jaeger, 1987). These contaminated food products will cause food poisoning to the consumer. From a total of 2242 FPE samples from 12 European food processing environment, *L. monocytogenes* was present in 32% meat processing facility (Muhterem et al. 2015). *Listeria* will survive if it does not follow good sanitation procedures. They are usually present in cold, wet drains within a plant. (Institute of Food Science and Technology, 2016). *Salmonella* is usually found from poultry. While *Listeria monocytogenes* occurs due to poor cleaning of machines, dirty floor and drains. Salmonellosis and listeriosis represent important foodborne diseases that continue to pose major challenges to national economic and public health. (Abatcha, 2017). Another problem which cause the mobilization of bacteria is the up and down cleaning motion and use of high pressure water jet, will cause the bacteria splashed to the process line (Makdesi, 2019). Food supplier pioneer food was fined 275k after in-house testing for the presence of *Listeria spp.* in their cooked products, the films have also committed to this mistakes (Matt, 2017). Table 2.7.1 below shows the characteristics of common pathogenic bacteria found in drain.

Drains may become the breeding ground for pathogenic and non-pathogenic micro-organisms. There is a high potential to transfer pathogens including Listeria monocytogenes from drains to food products. Biofilm is a protective structure formed in drains by microorganism such as Listeria, Salmonella and Escherichia coli where there is favor condition to them, they will grow and multiply rapidly. This biofilm is resistant to traditional sanitation chemical. Sometimes, clogged drains will create a positive air pressure inside the drain, where the bacteria may be transferred to preparation area through microbial aerosolization.

Table 2.7 1: Characteristic of common pathogenic bacteria found in drain

Pathogenic bacteria	Characteristics
Escherichia coli	It is a gram-negative, non-spore-forming, facultative, anaerobic, rod shaped, mesophilic bacterium that grows in 7–45°C. If consume food contaminated with pathogenic strain of E.coli, the person maybe experience symptoms such as severe stomach cramps, diarrhea, fever, nausea, and/or vomiting. They are found in human guts and most of the strains are harmless, except some strains such as Shiga toxin producing E.coli (STEC) can cause severe food borne diseases.
Coliform	It is a type of bacteria which is defined as the bacteria containing the enzyme enzyme β-galactosidase. They tend to ferment lactose to produce acid and gas at 35-37°C. They are present in surface water, soil or even animal waste. They are usually not causing serious illness, but is usually used to indicate the presence of pathogenic virus. Hence, they are also being called 'indicator organisms'.
Listeria monocytogenes	It is a foodborne pathogenic bacteria, the infection caused by this bacteria could be fatal. 20-30% of foodborne disease in high-risk categories people may cause death. They are active even in cold environment, even freezing does not stop their activities too. Listeria monocytogenes cause listeriosis, which is a condition where the bacteria infests your nervous system, cause infections such as headache, stiff neck, confusion, loss of balance and convulsions.

Flooding of wastewater above the drain can cause bio-aerosols, and lead to microorganisms transfer from drainage to the food . This will cause cross-contamination of food by bacteria such as *Listeria monocytogenes*, *Salmonella* and *E. coli*. Misuse and lack of maintenance of drainage also cause the transmission of water-related vector-borne diseases such as Malaria, and lymphatic filariasis (Madramootoo, 1997).

2.8 Drainage performance

Accoridng to EHEDG (2014) , two aspects indicated the performance of drainage system when established in food processing facilities namely;

1) Hydraulic performance i.e. its efficiency in removing wastewater in a given period
2) Hygiene performance i.e. cleaning efficacy that is measured based on soil residue including microbial level for post cleaning

2.8.1 Hydraulic efficiency and capacity

Hydraulic capacity is how much water a system can handle in a given time in the design, construction, and management of surface runoff, which is the flow rate of the surface runoff into the drainage. In our case, we need to evaluate hydraulic capacity based on the inlet flow rate as given in Equation 2.4.1 in Section 2.4. Higher hydraulic capacity of the drainage meaning that the drain can remove the waste water more effectively, and thus implies higher hydraulic efficiency due to their proportional relationship.

2.8.2 Hygienic performance

Drain cleaning has always been a problem (Abhishek, 2017). Cleaning generally is a combination of four factors: time, temperature chemical, and mechanical forces. There is no standard cleaning program for all food industry. Hence, cleaning program can be optimized by own company to achieve a result of most efficient cleaning yet low cost execution. Generic cleaning for drain is pre-rinse with low pressure water , removal of gross debris, removal of lipid, foaming and left for certain time and let the detergent to flow to the drain by gravity, mechanical brushing, intermediate rinse to remove remaining soil, sanitization, final water rinse, and use of sanitizer blocks in drain (Rotariu et., 2012). Smooth radius of drainage assists the removal of soil, effective cleaning of gully can be done with chemical and manual cleaning. (Fairley et al., 2014).

Cleaning efficacy is also affected by the surface finish of the equipment. Stainless steel surface of the drainage structure can help to resist abrasion which do not affect its hygienic properties. Surface topography (shape and features) affects cleanability if the crevice is large. Stainless steel with surface roughness (R_a, 5.38 μm) is unacceptable (Milledge, 2010). Roughness affects bacterial and soil adhesion after the cleaning process. The welding process of metals will a bit increase the roughness of the materials. Surface roughness, R_a with welding range from 1.97 to 4.56 μm. E. coli was also found to be more difficult to rinse. In conclusion, surface roughness of Ra less than 0.8μm was appropriate for stainless steel for food industry as recommended by The European Hygienic Engineering Design Group (EHEDG) and the American Meat Institute Equipment Design Task Force as Ra values below 0.8 μm surface topography did not affect cleanablity (Milledge, 2010).

Chapter 3:

Methodology

3.1 Case study profile

A frozen meat patties factory in Kajang, Selangor, Malaysia was selected for the case study and named as Factory Y throughout this study to keep the factory's anonymity. The factory is a Small and Medium Enterprise (SME) facility with an average capacity production of 1000-1500 kg patties/day and the factory operates for 8 hours daily. The factory is located in Industrial Park, Sg. Chua as shown in Figure 3.1.1 below:

Figure 3.1 1: Location of Factory Y

This premise is a single and half storey premise. The ground floor is dedicated to production only while the second floor is for administration. The neighbouring area consists of variety types of factories which can pose a hazard to Factory Y such as steel and aluminium factory, car workshop. There is no dwelling nearby or any nature element that can affect Factory Y. Factory Y produce various burger meat patties made of chicken, beef and lamb. Weight of each piece of patty ranges from 70 to 100 g/piece where the process flow is as shown in Figure 3.1.2.

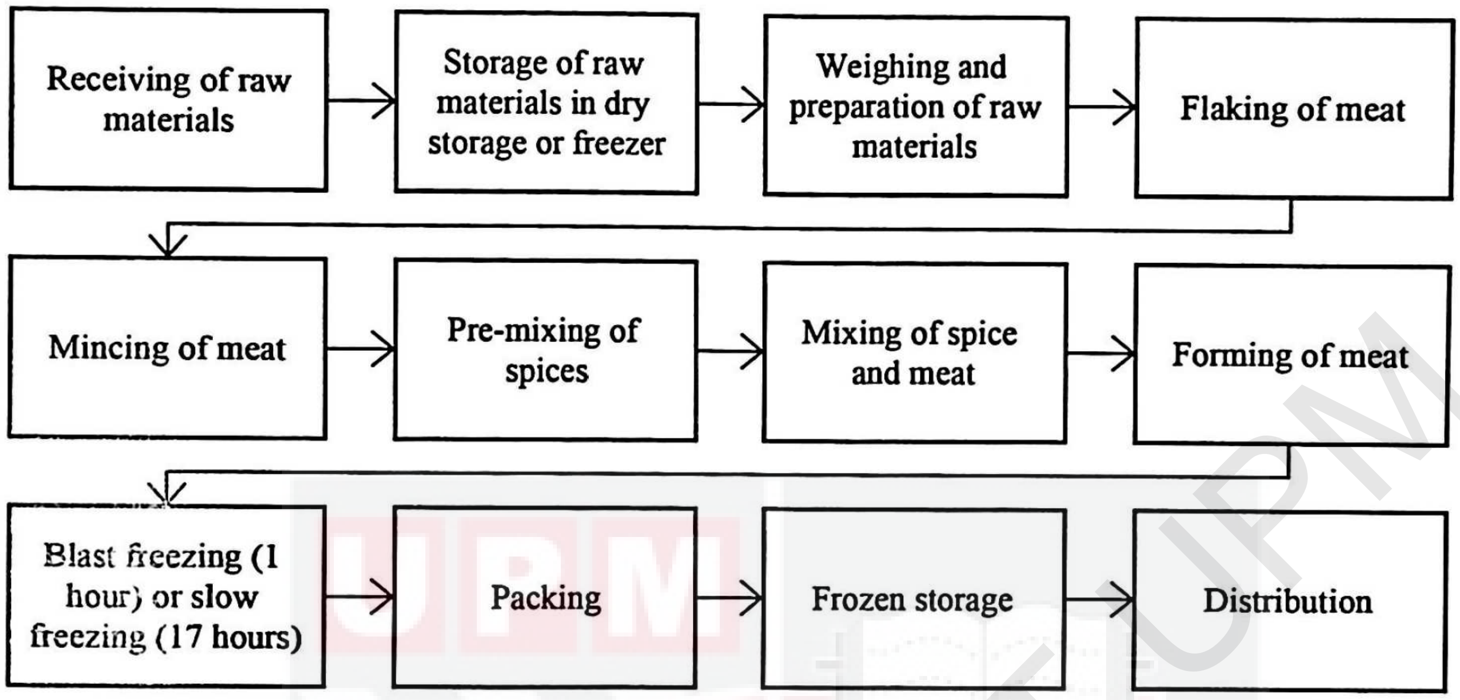


Figure 3.1 2: Process flow diagram for burger in Factory Y

Prior to the analysis of the drainage's performance, it is important to understand the company's profile and its current production. Information was collected through constant communication with the company's staff, site observation and document's revision. The following information were gathered:

1. Location of the building and the surrounding infrastructure
2. Product range
3. Production capacity per day
4. Operational hours
5. Layout of the factory and floor area
6. Process description and technology
7. Current wastewater volume and characteristics
8. Floor drainage structure and system, layout and maintenance program

9. Problem occurring regarding the floor drainage

3.2 Overall research methodology

The project consists of four stages which start with a site visit, data collection and problem understanding (Stage 1), followed by the hydraulic and hygienic analysis of gully drain in Factory Y (Stage 2) to achieve objective 1, development of design and installation checklist for gully in a meat processing area (Stage 3) to achieve objective 2 and lastly design of new drain model based on the design and installation checklist (Stage 4) to achieve objective 3 as shown in Figure 3.2.1.

Figure 3.2 1: Project flow of case study

3.3 Stage 2: Hydraulic and hygienic analysis of gully in Factory Y

3.3.1 Assessment of inlet hydraulic efficiency

The hydraulic analysis was required in this study as to investigate the factors contributing to inefficient removal of the wastewater from the floor surface that caused flooding during the production. An initial investigation found no blockage inside the drain pipeline and therefore, eliminating the reason that flooding was caused by interrupted wastewater flow inside the underground pipeline. It was suspected that the flooding was primarily due to inadequate inlet hydraulic capacity through the grating and poor location of the gully that reduces the rate of wastewater removal from the floor surface, and therefore resulted in hazard to workers.

There has been no analysis conducted with regards to inlet hydraulic of the drain for food processing. However, a study conducted by Gomez and Russo (2005) in the effort to increase the inlet hydraulic efficiency as to decrease the flooding risk and slippery among the pedestrians on the floor surface can be adapted to the study. Gomez and Russo (2005) described hydraulic efficiency of an inlets as the ratio of the wastewater discharge intercepted by the inlet to the total discharge approaching the inlet. This definition was translated into the Equation 3.3.1 for this study, whereby hydraulic efficiency, E, was understood as the ratio of the wastewater intercepted by the gully's grating, H_C, to the total wastewater approaching the drain, H_L, hydraulic load in L/s (flowrate) :

$$E = \frac{Hc}{H_L}$$

Where Hc represents hydraulic capacity i.e. discharge flow rate of the wastewater as intercepted by the drain in L/s and H_L represents the Hydraulic load i.e. discharge flow rate approaching the drain in L/s (applied on the surface of process area).

H_L was measured to be averagely 1.2 L/s which is assumed as 90% of freshwater supplied to factory Y. Since H_C operating under orifice flow when entering through the perforated holes on the grate, then the total grating open area and arising head control the H_C. Therefore, H_C can be determined using the standard orifice flow equation Equation 3.3.2 based on measurement of total open holes area, A, and head of wastewater above grate, h (Brater and King, 1976).

$$Q = C \times A \times \sqrt{2gh}$$

Where Q represents hydraulic inlet capacity or orifice (hole) capacity of grate (m^3/s), C represents the orifice flow coefficient with value 0.6 when the material thickness (=4.2 mm) is less than the orifice (hole) diameter (d = 10 mm), A represents the total opening area (m^2) of the grate (the total area available for flow), g represents the acceleration due to gravity (9.81 m/s^2), h represents the head above grating (m).

Detailed observation and investigation on the rising head and decreasing hydraulic load were performed for Drain 2 as in Figure 3.3.1 which is the only drain that functions to remove wastewater from production at current Factory Y.

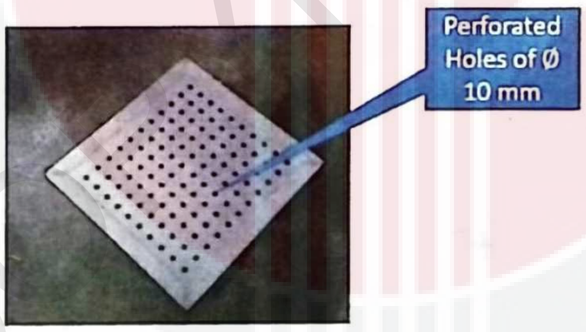


Figure 3.3 1: Drain 2

3.3.2 Assessment of hygiene

Since drain components in Factory Y receive large volume of waste water, they provide nutrients and an environment that is ideal for microorganism harborage and growth. The hygienic analysis of floor drains was evaluated based on cleaning efficacy, which is represented by the soil and microbial level after cleaning (Parisi et al., 2013; Fairley et al., 2014). In this study, two methods were used for investigating cleaning efficacy, namely 1) adenosine triphosphate (ATP) bioluminescence assay and 2) cultural microbiological method.

i. ATP bioluminescence assay

ATP bioluminescence assay is an analysis based on the measurement of ATP levels present on a surface after sanitation. Bioluminescence test exploits the chemiluminescence properties of luciferin-luciferase reagent, which reacts with any ATP residue present on a substrate, emitting light and measuring the presence of organic matter (Dancer, 2014). It is, therefore, an indicator of organic material presence, rather than microbial contamination. Some studies have found a correlation between ATP levels and total viable count (TVC) values (Amondio and Dino, 2014). A review on the use of ATP-bioluminescence in healthcare environments shows that the clean benchmark levels range from 100 to 500 RLU/100 cm^2 in healthcare or <500 RLU/100 cm^2 according to food industry practice (Amondio and Dinno, 2014).

In this study, the device used to measure the level of ATP on the drainage's surface was 3 M™ Clean-Trace™ NGi Luminometer (3 M, Era Bumi , Malaysia) as shown in Figure 3.3.2. It is a single-use test device containing a chemically impregnated reagent swab for the collection of a sample from a surface. The device contains a swab and the inactivated reagent inside a tube. The swab sample was brought to the Factory Y using a chill box to ensure the accuracy of the measurement. As instructed by the manufacturer, the swab was applied onto the area concerned with test area of 10 × 10 cm. The swab is rubbed against the area in a lateral direction, back and forward throughout the square area, in the meantime need to turn the swab to make sure the whole area of the swab is used for accurate measurement of ATP level. After taking each sample, the swab is put back to the tube without shaking or mixing the sample with the reagent and stored in the chiller box before analysis. Swab test were performed at welding of joint near edge, drain surface, holes after cleaning event (3 readings for every location and every event and average reading is calculated). The samples were immediately analysed using 3 M™ Clean-Trace™ NGi Luminometer (3 M, Era Bumi , Malaysia) which measures the amount of light generated by chemical reaction, and produces a result expressed in Relative Light Units (RLUs). The intensity of the light is proportional to the amount of ATP and therefore, indicates the degree of contamination.

Figure 3.3 2: ATP illuminator

The surface roughness of the drain surfaces can be determined visually and qualitatively. Quantitatively, according to Moerman and Wouters (2016), the recommended surface roughness of the surface to prevent microbial growth is $R_a \leq 0.8\mu m$ which indicates a smooth surface that is free from crevices and sharp edges. Higher R_a indicates present of rough surfaces, crevices and sharp edges that result in more difficult cleaning (Moerman and Wouters, 2016).

ii. Microbiological analysis

Sampling was carried out using the 3M Quick Swab containing Letheen Broth (3M, Era Bumi, Malaysia) after sanitation step as shown in Figure 3.3.3. Microbe test determines the amount of bacteria in a certain area to make sure it is within the safety limit. The swab was slowly and thoroughly rubbed three times over the surface area of drain (at welding of joint near edge, drain surface, holes and inside drain structure). At the end of sampling, swabs were placed in refrigerated containers and transported to the laboratory for analysis. In the lab, the swabs were vigorously shake for 10 seconds, to release bacteria from the swab tip. The entire contents of the tube were poured onto a 3M™ Petrifilm™ plate for culturing aerobic plate count (APC), *Listeria spp., Listeria monocytogenes and Salmonella spp.* After incubation periods, the colony forming units (CFU) on plates were counted.

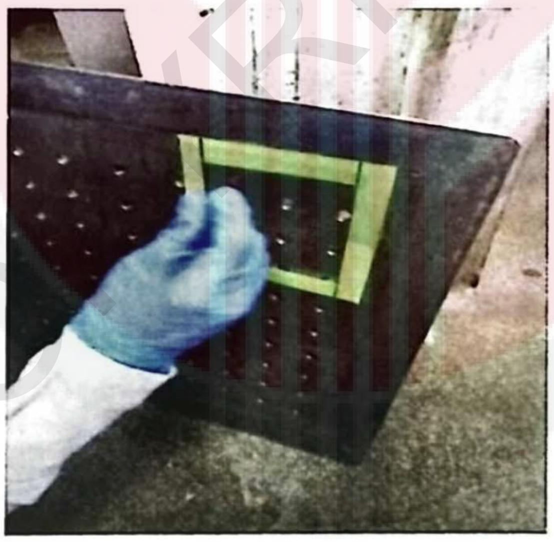


Figure 3.3 3: Swab sampling of drain 2 for microbe test

The following established and validated guidelines in Table 3.3.1 were used as a guide for evaluating the microbial results on the drain or environmental surfaces in food processing.

Table 3.3 1: Microbiological criterion of bacteria on food and non-food contact surface

Microbiological criterion	Guideline	References
APC	0 -10 CFU/cm^2	Wirtanen et al. (2012)
E. coli	0 -1 CFU/cm^2	Henroid et al. (2004)
Listeria spp.	Detection of *Listeria spp.* Indicates poor hygiene	Fairley et al. (2014)
Listeria monocytogenes	Presence of *Listeria monocytogenes* indicates public health concern	FDA (2019)
Salmonella spp.	Presence of *Salmonella spp.* indicates public health concern	FDA (2019)

3.4 Development of checklist for the design and installation of gully floor drain

Based on the resulted analysis of hydraulic and hygiene performance of the Drain 2, this study proceeded with the development of a checklist for the design and installation of gully floor drain in a wet meat processing. The checklist was aimed to provide a guideline for achieving an efficient functioning gully system with simultaneous consideration on the hygiene throughout its operation. The available criteria in the current guidelines on the general design and installation for drain were also reviewed and were consolidated with the evidence obtained from the hydraulic and hygiene analysis for the checklist development. The checklist was named General Checklist for Gully in Wet Areas for Meat Products divided into two parts which are design and installation. The design and installation criteria were developed and formulated based on this project's analysis as well as literature and currently available guideline review to achieve hydraulic efficiency and cleaning efficacy.

3.5 Checklist validation

The developed checklist was applied to the current Factory Y to determine the score obtained for the design and installation aspects. The scores obtained were used to validate the usefulness of the checklist in monitoring the design and installation of drain for this case study. However, in the future, the checklist needs to be validated in more case study samples so that statistical validation can be deduced for its practical usability.

3.6 Checklist demonstration

The developed checklist was used to guide the design of an efficient and hygienic drain model that suits the current production environment of Factory Y. Throughout the design process, items in the developed checklist Part A Design were checked progressively to ensure a correct drainage design could be obtained.

Chapter 4

Results and discussion

4.1 Process and Technology Description

The current production for the meat patties begins with the receiving of raw materials, flaking of the frozen raw materials, pre-mixing of dry ingredients such as textured vegetable protein (TVP) and isolated soy protein (ISP), mincing of meat, mixing of meat and pre-mixed ingredients, burger patties forming, blast freezing, packing and followed by frozen storage of finished products. Blast freezing is a rapid freezing process which rapidly cool the patties from ambient to temperature of -25°C in one hour in order to prevent the microbial growth while keeping the nutritional and sensory properties at high qualities. Nevertheless, the process is using high energy and the blast freezer is only used at the event where the products need to be delivered in a short time. Most of the time, the patties are cooled in cold room overnight and will be packed on the next day. The production processes is semi-automated with the partial process are conducted manually. The processing of poultry are generating high amount of hydraulic load to the only functional drain of Factory Y especially the flaking, mixing and mincing steps. Table 4.1.1 summarizes the information about the processing equipment.

Table 4.1 1: operation activities & objectives, processing equipment, water consumption and illustration of each process involved in making of burger patty

Process	Operation activities & objectives	Processing equipment	Illustration	Water consumption
1) Preparation of the raw materials	• Removal of packing materials and weighing • Weighing • Printing of the packing labels with expiry dates	Minor weighing : electronic scale (maximal loading: 5 kg) Major weighing : platform scale (maximal loading: 300 kg) Semi-automatic date printing machines : 60-120 times/min		No water is needed for this activity.

2) Flaking of the frozen raw materials	• Cutting of frozen materials (meat, fat and chicken skins) into 2 to 10 cm flakes for afterwards mincing without having to thaw • The reduced size avoids drip losses, bacterial growth and discoloration that often happen during thawing	Flaking: Flaker machine (2400 kg/h), compressed air necessary at minimum 4.14 bar Material transfer to the mincer machine: Euro bin (capacity 120 Litres)		Large amount of water is needed to wash off the meat flakes from the machine

3) Premixing of dry ingredients	- Mixing of the textured vegetable protein (TVP) and isolated soy protein (ISP) with cold water to produce finely comminute particle - The mixing was run for 5 minutes per loading by an operator in accordance to the recipe	Mixing: Bowl cutter (maximal capacity 33 kg/loading) Material transfer to the paddle mixer: Industrial tray of food grade 600 x 400 x 120 mm (capacity 23.7 Litres)		Medium amount of water is needed to wash the internal of the bowl cutter
4) Mincing of the frozen raw materials	- Refining of flakes from the flaker machine was into minces of the size 6 mm for round patty and 4.5 mm for oblong patty	Mincing: mincer machine (510 kg/h) Material transfer to the paddle mixer: Industrial tray of food grade 600 x 400 x 120 mm (capacity 23.7 Litres)		Large amount of water is needed to remove the minced meat flakes attached to the surface of machine

5) Mixing of all ingredients	- Mixing of the minces with the premixed TVP, ISP, starch and spices to obtain a homogenized patty batter (visual and texture check). - The mixing was run for 15-20 minutes by an operator in accordance to the recipe	Mixing: Paddle mixer (maximal 420 kg/loading)		Large amount of water is needed to rinse away the meat fragments
6) Forming of patties	- Shaping of patty into a definite size and weight – Visual check on the patty shape was carried out by an operator and adjustment was made to the mould whenever necessary. - The forming station required minimally three operators: insert the batter into hopper, manually stack the patties and lay the paper separator	Forming: Former machine (3600 patties/h), compressed air necessary at minimum 8 bar		Large amount of water is needed to lubricate the movement of the machine during processing

	between the patties - The patties were sampled periodically for microbial testing and also for cooking testing.			
7) Slow freezing in cold room	- Freezing of the patties (unpacked) in cold rooms for 17-22 hours in order to give them shape. - The patties were placed on trays, which were then stacked on trolleys			No water is needed and constant cleaning is required, which to remove the ice attached onto the flooring and wall.
8) Hand packing and boxing	- On the next morning, the frozen patties were retrieved from the cold room and brought to the packing station.			No water is consumed at this stage
9) Storage and shipping	The product were shipped to customer by company own trucks			No water is consumed at this stage

			(frozen storage)  (shipping)	

4.2 Current floor drainage system at Factory Y

All the processes are accommodated in a factory premise of around 30 m × 9 m for length and width measurement, while the height is 3 m. The factory's floor plan is shown in Figure 4.2.1 which shows the location of three floor drains namely Drain 1, Drain 2 and Drain 3. Location A and B are areas with severe flooding during production as shown in the floor plan in Figure 4.2.1. Based on the information by the production supervisor, the gully drainage was fabricated by company with no specific expertise in floor drainage for food processing. The drains are responsible to remove the waste water discharged during processing. Table 4.2.1 summarizes the location, features design, installation and application of the three floor drains.

Table 4.2 1: Location, features design, installation and application of the three floor drains

Drain No.	Illustrations	Features design				Installations and applications
		Dimensions in mm (L x W)	Grating Material and structure	Open Area, A, of Grate (mm^2)	Peripheral Fixtures	
1		304.8 × 304.8 mm	Stainless steel square grating structure with perforated round holes Ø 12 mm without frame	A – 49 x 113.10 mm^2 –5541.90 mm^2	• No edge-infill, filter basket, odour seal (water trap) • No gully body - Inner side without smooth contours, crevices that can harbour dangerous bacteria	• Drainage coverage for 5.4 m^2 floor area • Located in front of cold room • Not in use since the wastewater is not flowing to this drain
2		508×508 mm	Stainless steel square grating structure with perforated round holes Ø 10 mm without frame	A = 81 x 78.54mm^2 –6361.70mm^2	• Does not have peripheral accessories (spigot outlet, foul air trap (FAT) and sediment basket strainer) • Grating have no frame	• Installation for coverage of 29.6 m^2 • Falls are available only on two sides of drain • Application is for draining production clean down and equipment discharge • Grating not easy to remove, difficult for cleaning

						• Edge detail: no sealant and infill with crevices and void at the floor-drain-interface
3		• 508mm× 508mm (L x W)	• Stainless steel square grating structure with perforated round holes Ø 10 mm without frame	A – 110 x 78.54 mm² =8639.40mm²	• Without silt basket • Without gully inside	• Installation for coverage of 29.6 m² • Not in use since the wastewater is not flowing to this drain due to incorrect sloping (flooring fall) at the perimeter and no waste water discharge here

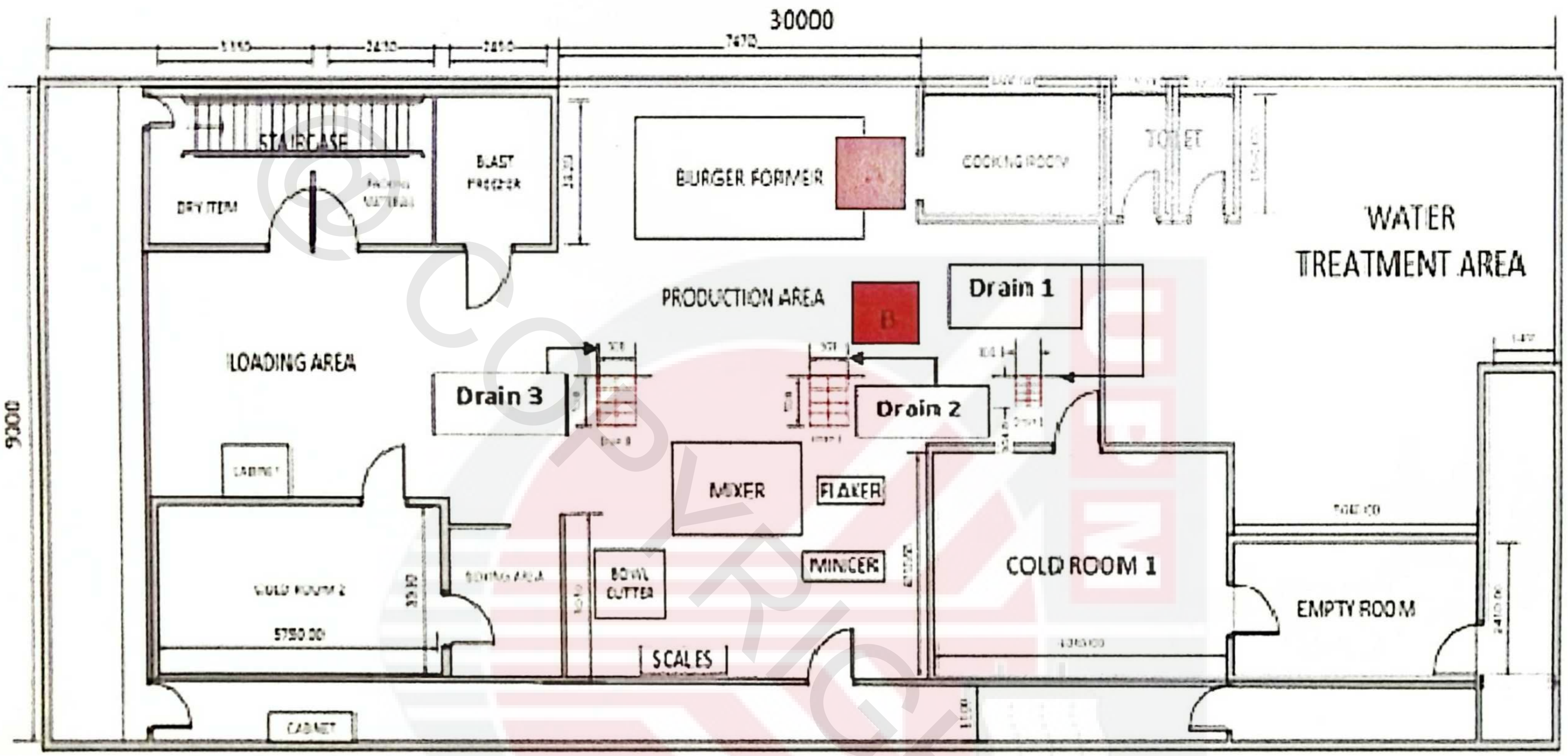


Figure 4.2 1 Floor plan at Factory Y with locations of Drain 1-3 and location (a) and location (b) that experience severe flooding during production

4.2.1 Wastewater in Factory Y

The wastewater produced by Factory Y is mainly based on two sources namely 1) equipment and utensil clean down 2) equipment discharge from former and flaker machines as shown in Figure 4.2.2. Wastewater discharged from meat processing contains high total organic content (TOC), biochemical oxygen demand (BOD) and total suspended solid (TSS), pH range from 7-8 which is optimum for microbial growth. All wastewater is directed to the wastewater treatment which is located at the back of factory. The average hydraulic load, H_L supplied for production at Factory Y was estimated at 1.2L/s.

Figure 4.2.2: waste water flow down from flaker machine

4.2.2 Subject of study: Drain 2

Based on our observation during the production and communication with the operators, only Drain 2 was used to remove the wastewater from clean down and equipment discharge. Poor gully design and installation of Factory Y are shown in Figure 4.2.3.

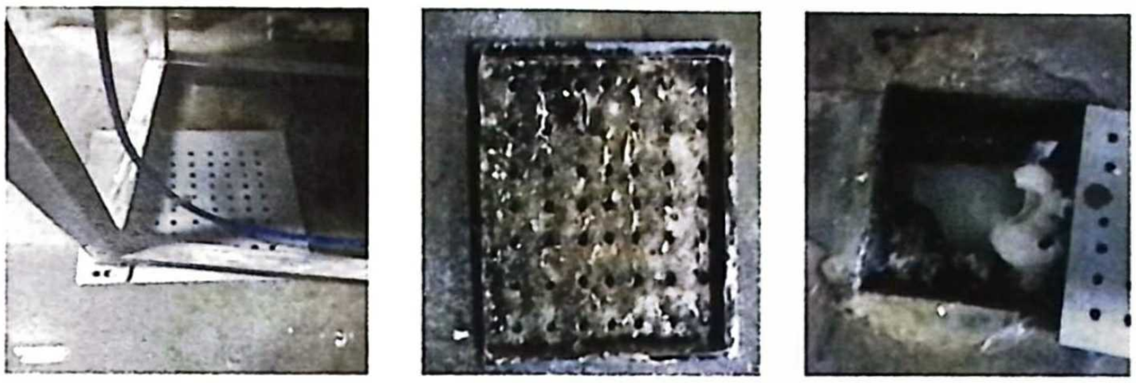


Figure 4.2 3: Poor drainage installation and design at Factory Y

Drain 1 and 3 were not in use due to the surrounding area that is not involved in wet processing. This was because the layout design for the drainage locations was not previously planned according to proximity to the wastewater source. Therefore, our study in the preceding sections are discussed with respect to only Drain 2. The cross-section for the Drain 2 structural design is given in Figure 4.2.4. Drain 2 was located under the flaker machine, with the size of 508 mm x 508 mm (L x W) and total open areas of 6361.70 mm^2 from 81 perforated holes. Drain 2 is to drain out the daily wastewater with maximum discharge flowrate of 1.2 L/s (maximum hydraulic load), sourcing from wall faucet for flooring area of 0.258 m^2.

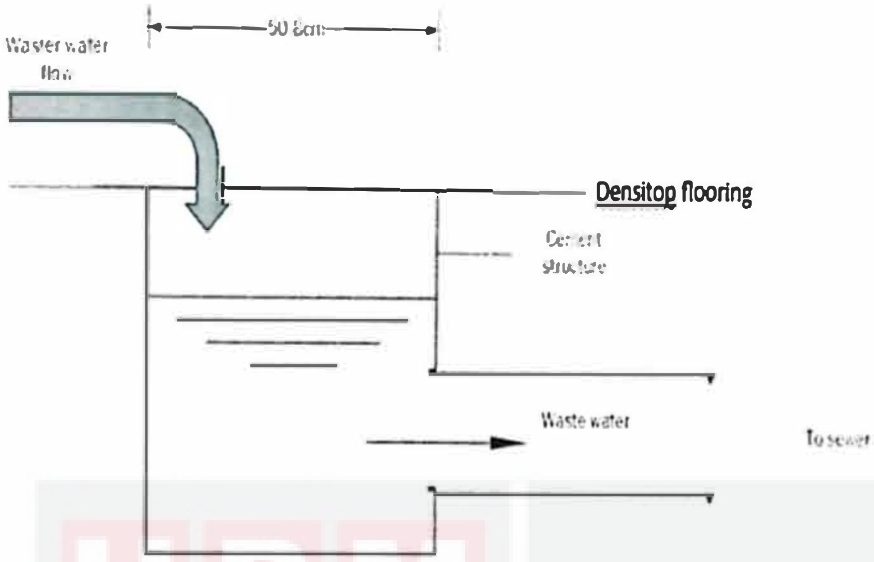


Figure 4.2 4:Cross-section for the Drain 2 structural design

4.3 Effect of gully's design on inlet hydraulic

The main lacking of the design was that the hole was designed to have diameter of 1 cm which become increasingly clogged during production operation and therefore, reduced the inlet hydraulic capacity, H_C . As production time progressed, increasing number of clogged holes of Drain Y was observed due to the size of meat remnants with average length ≥ 2 cm that flowed with the wastewater into the grating holes of $\emptyset = 1$ cm. The rise of wastewater above the grating becomes noticeable at head of 3 mm. These meat remnants were sourcing from meat offcuts at the flaker and former machines. As the water faucet was running continuously and constantly at flowrate of 0.0012 m3/s to lubricate the former machines, more blockages of the holes was observed. Simultaneously, increasing head was observed above the grating as shown in Figure 4.3.1, whereby when the head reached 5.0 mm the flooding was spread to Location A and B and at this time, the operators felt it was not convenient to traffic on the floor anymore and became cautious due to the risk of slippery. At head of 9.8 mm, the trafficking on the flood caused splashes and carry-over of the wastewater through trolley, operators outer garments and boots to other stations.

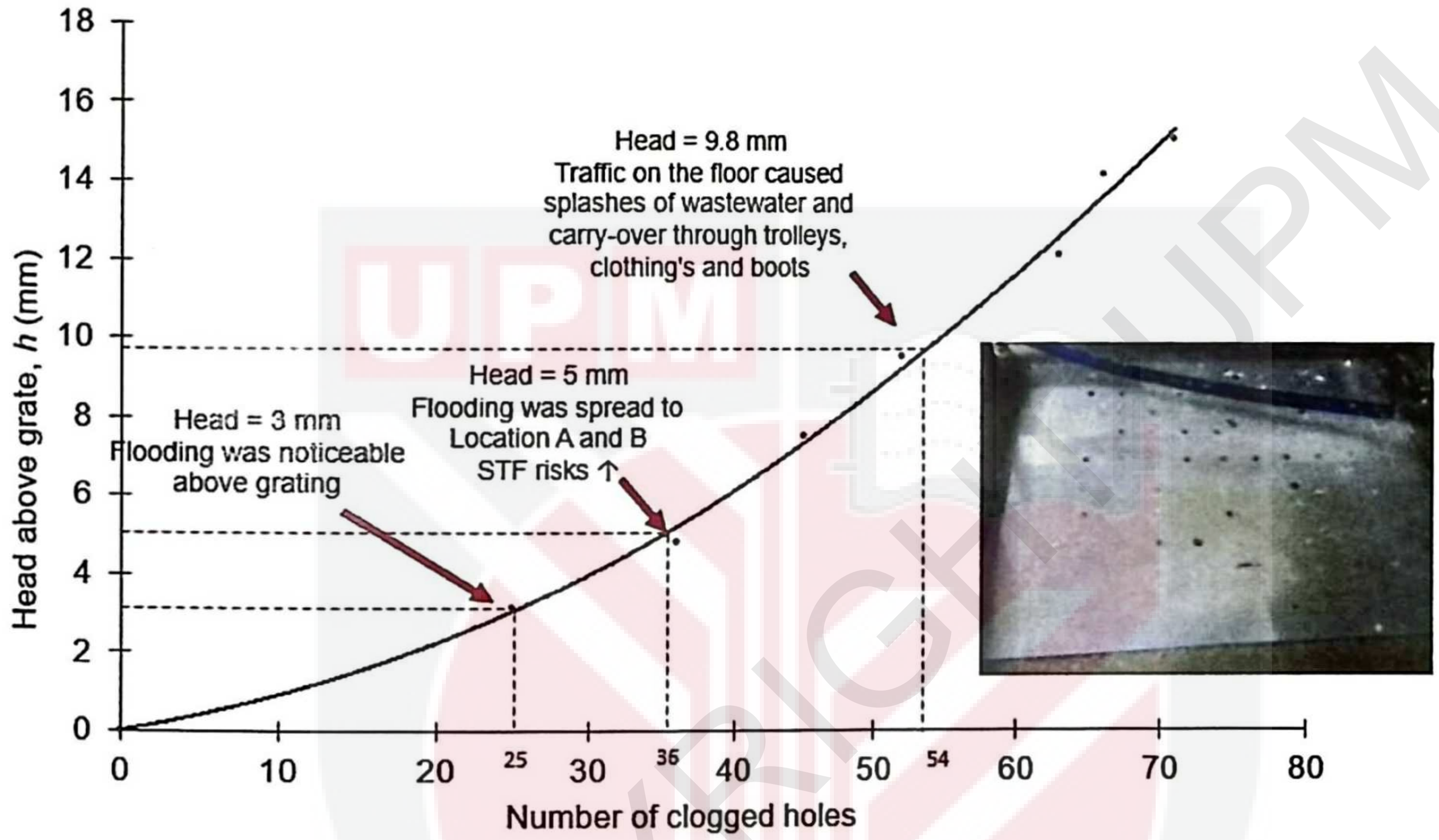


Figure 4.3 1: Graph of head above grate,h against number of clogged holes

Based on regression analysis, the polynomial-type curve was used to describe the effect of clogged holes on head above drain at range of 0 to 81 holes for this case study. The proposed model ($R^2 > 0.99$) described the strong positive relationship between head above Drain Y (H_Y) and number of clogged holes, n, is given by the Equation 4.3.1 when the faucet was not stopped and there was remaining unblocked holes at Drain Y:

$$h_Y = 0.0021n^2 + 0.0703n$$

Where h_Y represents the head of wastewater above drain, n represents number of clogged holes. Hence, based on Equation 4.3.1, if n reach maximum number of holes=81, the h_Y could reach up to 19 mm which was considered very hazardous and high risk of falling according to Winter (1992) and Pijnapel et al. (2001). At present, the operators were recommended to clean the drain shortly and remove the clog when the number of clogged holes reached 42 (50% of total holes) to 54 (67%) since this would give head rising from 6 to 9 mm. This recommendations was supported by the previous findings which have shown that changes in level of as little as 5 to 8 mm can potentially pose a hazard for the normal walking of fit healthy people (Winter, 2001; Chang et al., 2016). Nonetheless, this recommendation was also exhaustive, since in normal operation, Drain Y came to 50% clogging about 20 to 30 minutes after the forming machine started operating. Subsequently, one operator is needed to remove the clog and clean the drain for 5 to 8 minutes. When considering the total number of batch/day which was normally 4 batches, this cleaning took time about 60-96 minutes/day. This was a waste of production time and labor cost, and particularly crucial for small-scale premise, whereby labour cost at rate of $5/h is a major monthly operating cost.

As the flood was spread to location A (a) and location B (b), the maximal rise level of wastewater were taken for six sampling times during the peak production hour as shown in Figure 4.3.2. At location A (a) , the maximal wastewater head was 14.2± 0.8 mm while at location B (b), the head could reach maximally 15.1 ± 1.1 mm. Both locations as seen in Figure 4.3.2 were informed by the operators to be slippery and have incidences of falling down. Operators were also reported to be fatigued due to having to cautiously walking and there had been several incidences whereby the operators had almost lost balance and slipping. Floor surfaces of location B (b) was particularly hazardous since the aisle was travelled on most frequent in the factory (> 18 times/h).

Location A Location B

Figure 4.3.2 : Flooding at (a) location A and (b) location B

The increasing number of clogged holes has also reduced the inlet wastewater flowrate, Q, when determined using Equation 3.3.2 and therefore, a decreasing hydraulic efficiency, E, based on Equation 3.3.1 was obtained during the production as given in Table 4.3.1. In this case, the remaining total open area of Drain Y had a major control on the inlet flow rate, with a strong polynomial correlationship (R^2=0.99) than arising head (R^2=0.84), based on regression analysis. After 71 holes were clogged, the operators were observed to stop the operation shortly, and cleaning of the clog was performed.

Table 4.3 1: Changes in hydraulic efficiency of drain Y with increasing number of clogged holes

Number of clogged holes, n	Remaining total open are, A (m^2)	Head, h (m)	Inlet flow rate, Q (m^3/s)	Hydraulic efficiency, E (%)
25	0.0044	0.0031	0.00065	54.23
36	0.0035	0.0048	0.00064	53.33
46	0.0027	0.0075	0.00063	52.72
52	0.0023	0.0095	0.00059	49.17
63	0.0014	0.012	0.00041	34.44
66	0.0012	0.014	0.00037	30.98
71	0.0008	0.015	0.00026	21.37

The increasing blockages of the grating's holes had reduced the hydraulic efficiency of the drain down to 21%, at the end of observation, which implied that 79% of wastewater was not removed and had flooded the other locations during the production time. Hence, Drain Y was not efficient in removing the wastewater during the production. With such a severe wet flooring, operators claimed that the flooring was still wet on the next day if cleaning is not thoroughly done. This was particularly a concern, as the damp environment could provide an ideal condition for microbial growth and pest attraction.

4.4 Effect of gully's design and installation on hygiene

Drain Y showed lack of hygienic design. There have been found that numerous crevices and pit growth on the surfaces, dead space at the floor-drain interface due to absence of hygienic edge profile which harbor the growth of bacteria and microorganisms. Besides, drain Y is not installed with gully body, but is made of concrete (flooring materials) which is not protected by any screen. No filter basket is available to capture the solid waste. Besides, drain Y has no water trap to prevent the escape of foul air into the surrounding, and also no frame to hold the grating.

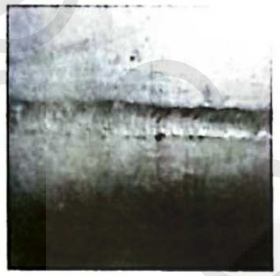
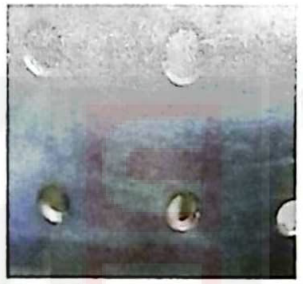
With such poor design, Drain Y could not be effectively cleaned even when the disinfectant was used. In addition, Drain Y was inappropriately installed below the cutting equipment as seen in Figure 4.4.1 due to negligence in reconciling the plant and plumbing layout design. It was therefore difficult to access Drain Y for frequent cleaning and maintenance. The grating is installed directly on the flooring surface and was not supported by stainless steel frame, which caused the drain edge to be above the floor surface and led to continuous accumulation of soils around the drain as shown in Figure 4.4.1.The intricacies of the overall cleaning process has also demotivated the operators on performing the cleaning of Drain Y, whereby in one incidence the clog were not cleaned at all until the next day of production.

Figure 4.4 1: accumulation of soils at floor-drain interface

Table 4.4.1 shows the mean ATP results (RLU) and microbial count as determined for the different point of Drain Y after the cleaning procedure. The clean benchmark was <500 RLU/100 cm^2 and applied for this analysis (Amondio and Dinno, 2014).

Soil water inside the gully body has high aerobic plate count (APC) is 8.1×10^4 CFU/cm^2 followed by 2.4×10^6 CFU/cm^2 in grating surface, 4.5×10^6 CFU/cm^2 in perforated holes, 5.3×10^6 CFU/cm^2 in drain edge.The highest ATP values were also recorded for the soil water inside the Drain Y body, followed by drain edge, hole surfaces and grating surfaces. On the other hand ,high level of Escherichia coli(1 CFU/cm^2) was found in the soil water inside the drain, 25 CFU/cm^2 in grating surface, 2 CFU/cm^2 in perforated holes, 17 CFU/cm^2 in drain edge The inner surface of Drain Y body was highly contaminated due to multiple reasons. The absence of filter basket allow the solid waste including the fats and proteins to sediment on the body's surface. The acidic nature of animal fat and proteins waste had attacked and corroded the unprotected concrete, weakening their structures and breaking them down little by little. Additionally, the acidic compounds reacted with the alkaline cement paste, which was the binder for the concrete structures and making it vulnerable to damage from abrasion, hot water cleaning, and further chemical attack. Such impacts had left the surfaces underside to be uneven with crevices and many dead spaces that could not be effectively cleaned and thus, had entrapped and accumulated organic soil, giving highest ATP value of 11657.

Table 4.4 1: ATP reading (RLU/100cm2), APC, E. coli, Listeria spp., Listeria monocytogenes and Salmonella spp. (CFU/cm2) at various point of drain Y

Surfaces of drain	Grating surface	Drain edge	Hole surface	Inside drain body's surface
Surface illustrations				
ATP-bioluminescence assay (RLU/100 cm^2)	3793	10846	5484	11657
APC (CFU/cm^2)	2.4×10^6	5.3×10^6	4.5×10^6	8.1×10^4
E. coli (CFU/cm^2)	25	17	2	1
Listeria spp. (CFU/cm^2)	Detected	Detected	Detected	Detected
Listeria monocytogenes (CFU/cm^2)	Not detected	Not detected	Not detected	Not detected
Salmonella spp. (CFU/cm^2)	Not detected	Not detected	Not detected	Not detected

As can also been seen in Table 4.4.1, aged off-white fat deposits that shows thick greasy in texture and water-repellant (hydrophobic) characteristics was observed on the inner surface of gully body. The build-up of this fat deposits contained unsaturated fatty acids which has been oxidized or polymerized due to exposure to air for some time and became harder and closely bonded on the concrete surface. Since fat and greasy deposits contain hydrophobic molecules, the surface enables the bacterial cell-surface which possesses hydrophobicity (due to fimbriae, flagella and lipopolysaccharide) to attach and therefore, could form biofilm. Biofilm is a thin but robust layer of mucilage adhering to a solid surface and containing a community of bacteria and other microorganisms which are more resistant to disinfectants. According to Giaouris et al. (2014), the biofilms formed by pathogenic and spoilage bacteria may create persistent source of product contamination, leading to serious hygienic problems and also economic losses due to food spoilage.

Drain edge also recorded too high contamination with high ATP reading 10846 RLU/100 cm2, highest APC count of 5.3×10^6 CFU/cm2 and high amount of E.coli (17 CFU/cm^2)which is as well as Listeria spp.. The drain edge was highly creviced, poorly finished with many sharp corners that accumulated soil could not be effectively removed after cleaning. Similar sharp and rough finishes were also observed for the holes and grating surfaces, and hence, implying the same reason for ineffective cleaning of organic soil and microbial counts. The recommended surface roughness for meat contact surface equipment is Ra<0.8µm (EHEDG Doc 44, 2014). Too high surface roughness as definitely illustrated in all of Drain Y's surfaces has hindered the cleaning process. Nonetheless, the presence of E.coli and Listeria spp. were still concerning as these violated the guideline of microbes limit on food and non-food contact surfaces as in Table 3.3.1.

The recorded APC was unacceptable with 2.4 x 10^6 CFU/cm^2on grating surface, whereby *Listeria spp.* and *E. coli* was also present. During the flooding on the floor, there was a clear potential for motile pathogens to migrate from colonized areas in the drain to Location A(a) and Location B(b).Highest level of E coli was recorded at grating surface (25CFU/cm^2) and Listeria spp is detected. E coli was not removed during cleaning operation as they are able to surve in large range of temperature (7-45 °C) In all cases, Listeria monocytogenes and Salmonella spp, were not found (three sampling times). The result proves the formation of biofilm on grating surface which cannot solely removed by mechanical cleaning action.

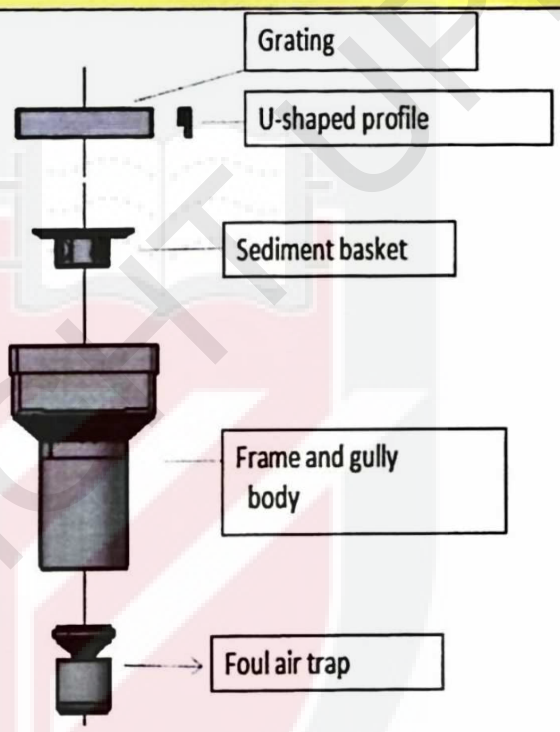
Listeria spp. was reported to be able to survive and grow at low temperature with consequent adverse effects in the ready-to-eat food processing (Chang and Wiedman, 2009; Fairley et al. 2014). The species was noted for its ability to form biofilm as it readily adheres to surfaces. With these capabilities, drain surfaces when not cleaned effectively provided important niche for the resilience of Listeria and can be a source of contamination in the processing plant environment and possibly in food products. Meanwhile E. coli is a common indicator of fecal contamination, whose detection on surfaces is important for hygiene monitoring. Due to increasing stringent microbiological requirement, the presence of E. coli in RTE foods has caused subsequent rejection of finished products and substantial economic losses to the food producer (Keeratipibul et al., 2009). One of the possible food contamination routes is via aerosol created by use of a high-pressure water hose when cleaning and sanitizing floor and drains. The aerosol with microbes spread onto cleaned food contact surfaces and contaminated the meat products (Keeratipibul et al., 2009). It is known that meat products provides a preferable environments for verotoxigenic E. coli and this microorganism produces significant amounts of verotoxins in contaminated meat kept in 37°C. Several reports have found that intoxication through consumption of undercooked minced meat, sausages and RTE-food contaminated with E.coli, sourcing from hygiene failure (Ekici and Duemen, 2019). While the meat is cut into pieces as commonly occur in the production , the E. coli on the surface of the meat reach the inner sections and can stay alive if a sufficient heat treatment is not applied, turning it into a risk factor for consumers (Miller et al., 2018; Ekici and Duemen, 2019).

Worryingly, the flooded area are located at the path where trafficking is frequent by operators and also by wheeled trolleys (>15 times/day). The wastewater flood was rich with heavy loads of fats, oils, grease and solids and therefore, the possibility for the microorganism such as *Listeria monocytogenes* and *Escherichia coli* to grow during the production at this area is high as the ambient temperature is averagely at 27 to 28°C. Flooding of drains causes microorganisms on the surface to become aerosolized and air disperses them, causing increased levels of aerosolized bacteria. Besides that, the presence of bacteria can also be detected with smell, in which the microbial growth was one of the main reason for the development of off odor (Hempell et al., 2011). In a nutshell, the design and installation faultiness has limits the drain's cleaning performance.

4.5 Checklist for gully's design and installation in meat processing

Table 4.5.1 shows the checklist that can be used to guide the designing or selection of gully's design in a wet areas for meat products. User is able to tick √ if the criteria is met in the "Yes" column. When the criteria is not relevant, user can tick for "NA" column for not applicable. Every "Yes" tick was scored with 1 point, while no point was given for "No" tick. When the criteria is not relevant, user can tick for "NA" column for not applicable. The salient components of the developed checklist are namely 1) availability of the minimum components, 2) design parameters with their design matrix and sequence and 3) design procedures.

Table 4.5 1: Checklist for design of gully in a wet processing facility for meat products

GULLY'S DESIGN CHECKLIST IN WET AREAS FOR MEAT PRODUCTS	
Minimum major components checklist.	**Illustrations**
Tick X for available components in the design. A. Grating [ ] B. Frame [ ] C. Silt basket [ ] D. Foul air trap [ ] E. Gully body [ ] F. Piping [ ]	

General criteria		**Yes**	**No**	**NA**	**Remarks**
1	All minimum components are available in the drain design				
2	All components are made of stainless steel AISI304 *If use chlorine disinfection, AISI316 is recommended				
:3	Full pickle passivation for the				

			Yes	No	NA	Remarks
		drainage components				
Features of the components						
Part A : Grating			**Yes**	**No**	**NA**	**Remarks**
4	A1	Surface roughness average for the drain, $R_a < 0.8\mu m$ **OR** all surfaces comply to the following designs: • Continuous welding of joints • No crevices and dead-end • Rounded or radiuses corners (minimum radii of 3 mm)				
5	A2	Non-slip grating				
6	A3	Removable grating with ladder grating or cast grating with rounded corners and no weld				
7	A4	Open grate area (A) and drain dimensions corresponds to maximal hydraulic capacity requirement + allowance: $A = \frac{Q}{0.6 \times \sqrt{2gh}}$				

		Q = maximal hydraulic capacity requirement + 100% allowance X L/s Cd = 0.6 $g = 9.81 m/s^2$ h = 0.005 m (maximal head allowed) • Example when Q = 0.0012 m^3/s $A = \frac{0.0012 \ m^3}{0.6 \cdot \sqrt{2 \cdot 9.81 \cdot 0.005}}$ $= 6.39 \times 10^{-3} \ m^2$ $= 6390 \ mm^2$				
8	A5	Grating should have load class according to loading classification: • Light duty : Grates test under 900 kg • Medium duty: Grates test 900-2250 kg • Heavy duty: Grates test 2250-3375 kg Extra heavy duty: Grates test 3375-4500 kg				
Part B : Frame			**Yes**	**No**	**NA**	**Remarks**

9	B1	No void space between floor and frame e.g. U-edge profile that embedded deep inside the concrete				
10	B2	Minimal thickness of 5mm				
Part C: Silt basket			**Yes**	**No**	**NA**	**Remarks**
11	C1	Removable silt basket for easy cleaning				
12	C2	Appropriate area opening to capture solid soil but not affect the hydraulic capacity				
13	C3	No dead space, crevices and rough surfaces				
Part D : Foul air trap			**Yes**	**No**	**NA**	**Remarks**
14	D1	Removable water trap with water seal height minimally 50 mm				
Part E : Gully body			**Yes**	**No**	**NA**	**Remarks**
15	E1	Surface roughness average for the drain, $R_a < 0.8\mu m$ **OR** all surfaces comply to the following designs: • Continuous welding of joints				

			Yes	No	NA	Remarks
		• No crevices and dead-end Rounded or radiuses corners (minimum radii of 3 mm)				
16	E2	Dry sump to avoid accumulation of water				
Part F : Piping to sewer			**Yes**	**No**	**NA**	**Remarks**
17	F1	Vertical spigot outlet is recommended with 45° swept bend				
18	F2	Back flow prevention				
19	F3	The size of the piping can be determined through equation below, nominal pipe size (NPS) table as ASME B36.19 and design stress table for stainless steel pipe as attached in appendix. $Q_C = v \times (\pi \cdot \frac{D_i^2}{4})$ $Q_C = hydraulic\_capacity$ $v = velocity\_of\_flow@opening$ $D_i = inner\_diameter$ $Schedule\_number = 1000 \times \frac{P}{S}$ $P = design\_pressure$ $S = design\_stress$				

		$D_O = D_i + 2 \times t$ $t = thickness\_of\_pipe$				
		Total				

Meanwhile, Table 4.5.2 shows the checklist for installation of gully in a wet areas for meat products. The checklist was developed based on the insights gained through this analyses and have been consolidated with the available guidelines. Every "Yes" tick was scored with 1 point, while no point was given for "No" tick. When the criteria is not relevant, user can tick for "NA" column for not applicable. The salient components of the developed checklist are namely 1) availability of the minimum components, 2) design parameters with their design matrix and sequence and 3) design procedures.

Table 4.5 2: Checklist for installation of gully in wet areas for meat products

GULLY'S INSTALLATION CHECKLIST IN WET AREAS FOR MEAT PRODUCTS				
No	Detail	Yes	No	Remarks
1	Proximity to the wastewater source distance at most 5m			
2	Location of drainage is accessible for cleaning, inspection and maintenance			
3	Location when possible avoids traffic. If unavoidable, the drain must resist applied			

	load and turning stress			
4	Gully's design fit to be installed in the flooring. E.g. Square gully for tiles and resin flooring, rounded gully for resin and vinyl flooring			
5	Gullies are secured in the floor with anchor			
6	Frame has to be installed below the final floor layer			
7	Flooring material around the frame is increased and use of appropriate sealant at floor-drain-interface			
8	Drain receive falls from 4 sides with floor sloping of 1.5 -2 %			
9	Square gully must be installed with shaped edge profile • 1.5 mm steel thickness • Fillant is of waterproof material • Frame height is deeper than flooring layer (10-20 mm)			
10	In multiple-storey building, where the drain is located above ground level			

	• Use of membrane to prevent possible water penetration to the lower ceiling • Drainage piping must be double-walled when penetrate into hygienic area and made from non-flammable material.			
11	Drainage layout allows wastewater to flow direction from high risk to low risk are			
12	Piping layout with swept tees and soft bend to allow wastewater moving towards cleaning well that is positioned outside hygienic area.			
	Total "Yes" and "No" out of 12 criteria			

4.6 Checklist validation based on Factory Y

Both checklist can be applied to any commercial and fabricated drain model. When this checklist was applied to the current Factory Y as given in Appendix 1, the Factory only shows 16.67% compliance for the the Design Checklist, while 27.27% for the Installation Checklist in Appendix 2. Based on analysis in Section 4.2 and 4.3, the hygiene problem and hydraulic inefficiency arised due to poor design and installation. Hence, the low scores of Factory Y has validated the usefulness of the checklist in monitoring the design and installation of drain for this case study. However, the checklist need to be validated in more case samples in the future so that statistical validation can be deduced for its practical usability.

4.7 Design checklist demonstration

The Design Checklist was also applied to guide the designing of a correct new gully for Factory Y as in Appendix 3 and Appendix 4. The overall design for the gully structure generated using Autocad is given by Figure 4.7.1.

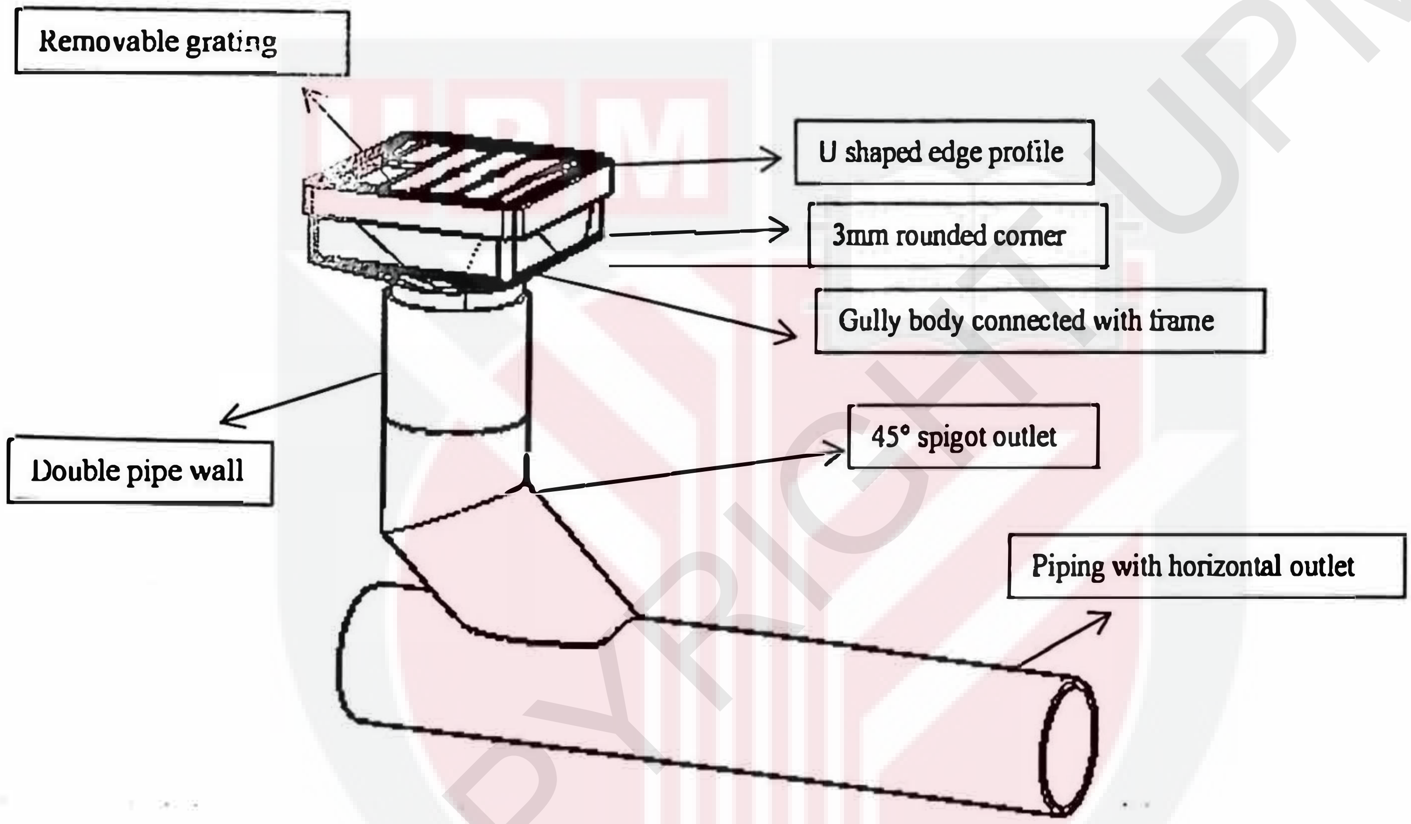
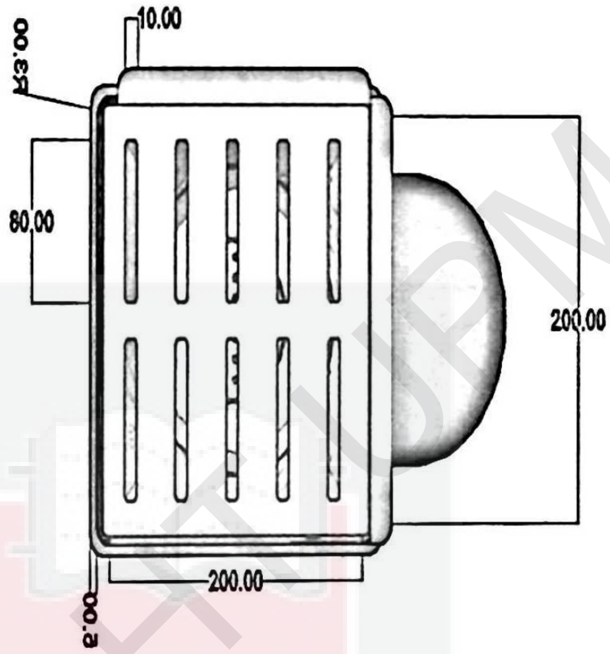
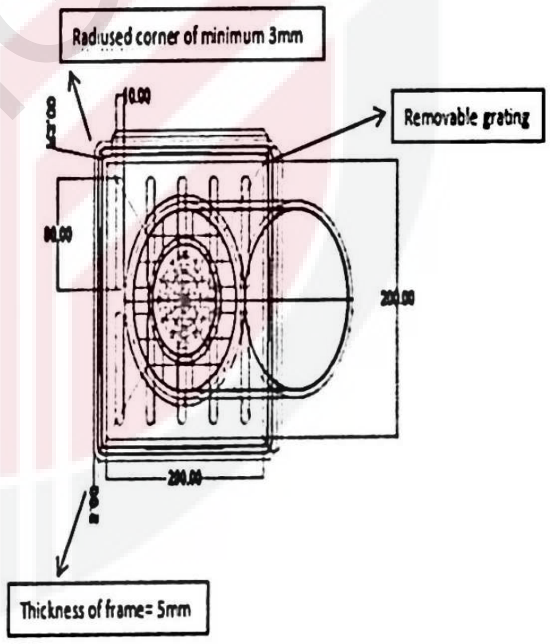
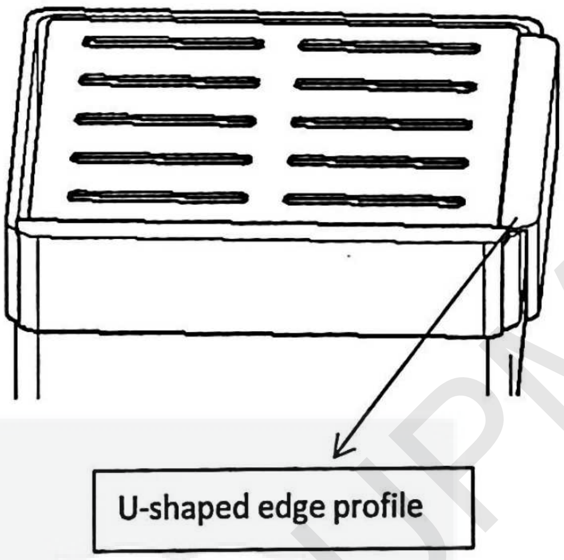
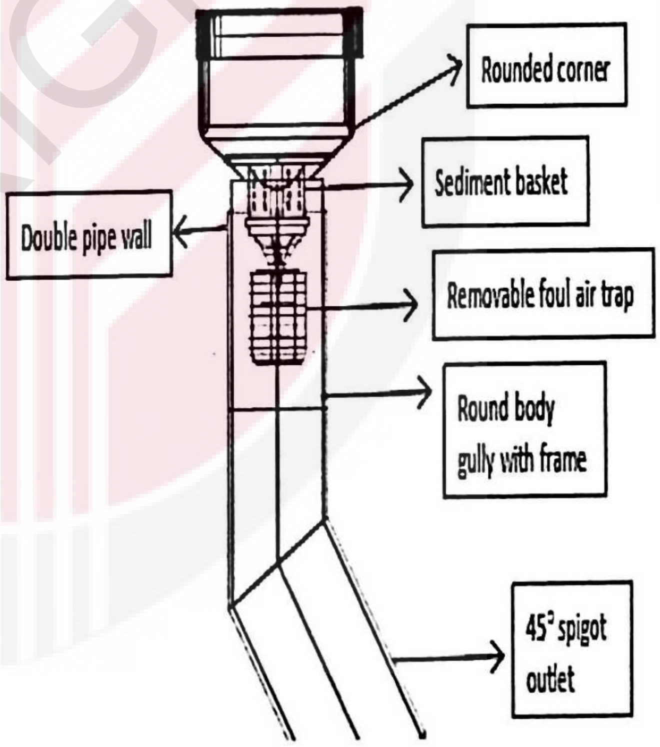


Figure 4.7 1: Overall 3D structure of the designed drain

The features of the designed gully are that the drain structure is made of stainless steel AISI304, with full pickle passivation. Full pickle passivation will be done for the drain to remove contaminants and assist the formation of continuos chromium-oxide, passive film. The surface roughness, R_a of the drain is less than $< 0.8\mu m$. Too high surface roughness will hinder the cleaning process, rough surface is usually indicated by the presence of pits and crevices where the bacteria can hide themselves in. Back flow prevention is located in between the drain and sewage system. The drainage act as a environmental surface, hence back flow is required in between the environment and sewage system. Bacteria from the sewage system can reach the environment and contaminate the food through improper drainage system Several important design features of the new drain that differed from the current Drain 2 , were summarized as in Table 4.7.1

Table 4.7 1: Design features of new designed drain

Design details	Design drawings
• *Removable, and non-slip ladder grating with square frame of thickness 5mm.* The minimum thickness is to ensure the structure can withstand the weight on it such as the loaded trolley. The grating should be easily removable to facilitate cleaning and inspection process, with appropriate recommended surface roughness. • *Rounded corner with minimum radius of 3mm* The rounded corner provides easy-to-clean and safety features	

• *Edge-in fill* Resin is filled at the floor-drain interface to prevent the accumulation of waste water which encourages bacterial growth, the empty space between the floor and drain allows waste water to seep in. U shaped edge profile is used to separate the frame and flooring completely, to prevent waste water accumulation inside dead space.	
• *Round body gully instead of mortar body* The round body gully is combined with frame which is made of stainless steel, to contain sediment basket and foul air trap. • *Removable sediment basket and water trap* The sediment basket and water trap must be removable for regular cleaning session, thorough cleaning is required for these components as biofilm will developed as waste water flows through it. • *Double wall pipe* The transfer piping is double wall to resists the thermal shock, sudden change in	

temperature of fluid inside the pipe. • 45° spigot outlet The 45° bend in the outlet allows easy mechanical cleaning or jet cleaning of the piping system	

As for the installation, the following aspects must be adhered. (1)Production floor must be increased around the gully.Flooring around the drain is increased to increase the flow as the sloping of the floor increase. Steep surface can improve the flow across the drain. (2)Silica gel is filled at the floor drain interface.Silica gel as the common fillant at floor drain interface is waterproof which can block the flow of solid meat waste or waste water flow into the gap space. (3) Frame is fixed at the flooring with two 2mm screw lock.The frame is fixed with screw above the drain. During the cleaning process, screw is removed to open the drain.(4) The drain should not be installed under the machine, near to the water sauce, and receive 4 falls. The gully should be installed at an appropriate place to receive 4 falls, to make use of its full hydraulic capacity. (5) The frame is installed below the final flooring layer.The frame is installed below the final flooring layer, otherwise the flow of waste water will be impeded by protrusion of the drain on the surface.(6) The pipe is fitted and sealed properly at the outlet. The piping is sealed and fitted properly with the gully body to prevent leakage of waste water. (7)The drain in installed in a direction so that it flows from high risk to low risk.The drain is installed at a direction of flow from high risk to low risk, to prevent the contaminants from the low risk place such as meat preparation area flows to high risk place.(8) The outlet piping is installed with minimum gradient to allow efficient flow of waste water. The outlet piping with appropriate diameter connected to gully body vertically and followed by a 45° spigot outlet to make sure efficient flow rate inside the pipe. The flow of fluid also influenced by pipe size and their orientation. If the outlet piping is horizontal, then minimum gradient is required for efficient flow.(9)The gully installation is installed according to the installation manual as in Table 2.6.1.The gully should be installed based on the instruction manual to make sure it is installed in a correct way to perform the drainage's functionality when it is installed. Physical fabrication and installation of the new drain was not proceeded due to time and cost limitation. These are recommended to be continued in the next projects based on the design and installation information obtained from this project.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Evaluation of the effect of design and installation of floor drainage on hydraulic efficiency in a meat processing facility

The results recognized that hydraulic efficiency depends on area of opening, sloping of floor. The open area of floor Drain 2 at Factory Y(6361 mm^2) is less than minimum required area calculated using the formula of hydraulic flow rate (6390 mm^2). The design of the Drain 2 is a simple gully made of mortar covered with a rough grating. Besides, there is no increased flooring around Drain 2 cause the flow of waste water at Drain 2 is slow. As if the flow of water is non-stop, which the tap is not closed, the area of opening of the grating were clogged and getting smaller and flood level (head) will starts to increase. The flooding level can be up to maximum value of 1.5cm at production area, which is considered high . The flood condition has makes the walking movement of operators difficult and thereby affects the working efficiency,while safety of the workers is also compromised. Flooding cause the surface become slippery, which poses the risk of falling down. Drain flooding are sources of viable aerosol which lead to risk of cross-contamination. Based on the analysis of hydraulic efficency of drain Y, the head of flooding and number of clogged pores shows a strong positive relationship on a polynomial curve with $R^2 >$ 0.99., The hydraulic efficiency of drain Y drops from 54.23% to 21.37% corresponds to 25 clogged pores to 71 clogged pores in just 40 minutes. Meanwhile the head of flooding is also increased from minimum of 3.1cm increased to a maximum value of 15cm. The 15cm height of flooding level pose a high risk to slip, trips and falls down. Hence, The faucet has to be stopped to prevent further increase of flooding head and sweeping will be carried out by operators manually.

5.2 Evaluation of the effect of design and installation of floor drainage on hygiene in a meat processing facility

Based on results, Drain 2 has no hygienic design with high surface roughness, non-rounded comers, surface with perforated holes and crevices, no edge infill at floor drain interface and no gully body made of stainless steel. The measured ATP reading was highest for drain edge (10846 RLU/100cm^2) followed by perforated holes(5484 RLU/100cm^2) and grating surface (3793RLU/100cm^2) which do not meet the benchmark for food industry which is less than 500 RLU/100 cm^2.

The microbiological test measured the 1) aerobic plate count (APC), 2) *Escherichia coli*, 3) *Listeria monocytogenes* and *Salmonella spp.* based on culture method. The aerobic plate count is the highest which is 5.3×10^6 CFU/ cm^2 in drain edge, followed by 4.5×10^6 CFU/ cm^2 in perforated holes, 2.4×10^6 CFU/ cm^2 in grating surface and 8.1×10^4 CFU/ cm^2 in the soil water inside the drain.

On the other hand, the level of Escherichia coli in soil water is recorded as lowest of 1 CFU/ cm^2 in the soil water inside the drain, followed by 2 CFU/ cm^2 in perforated holes, 17 CFU/ cm^{2}in drain edge and the highest in grating surface of 25 CFU/ cm^2.,While for all the samples, Listeria spp was detected in the sample , yet without the pathogenic Listeria monocytogenes, and Salmonella spp was not isolated.

The surface of the grating should not contain microbes to make sure food safety and hygiene as microbial contamination of food will also occur through bio-aerosols transmission especially drain 2 is a frequent traffic area.

5.3 Proposal of design and installation checklist for floor drain in a wet areas for meat processing

Based on the results obtained, a design and installation checklist of gully in wet meat processing area has been proposed. The checklist will be useful when it comes to setting up a drainage system in a meat processing facility. The design checklist was divided to 2 parts which are : 1)Design part, and 2) Installation part.

Meanwhile, the installation checklist was divided to 12 criteria including drain proximity to water source, location for easy cleaning, inspection and maintenance, avoids traffic. gully secured on suitable flooring, frame is installed below the final flooring layer,flooring material around the frame is increased and use of appropriate sealant at floor-drain-interface, drain receive falls from 4 sides with floor sloping of 1.5 -2 % ,Square gully must be installed with shaped edge profile, drain is located above ground level in a multiple-storey building, drainage layout allows waste water to flow direction from high risk to low risk area, piping layout with swept tees and soft bend to allow waste water moving towards cleaning well that is positioned outside hygienic area.

On the other side, the design checklist was divided into 19 criteria which includes all minimum required components, made of stainless steel 304, fully pickle passivated for the drainage components, surface roughness,$R_a < 0.8\mu m$, non-slip, removable grating with ladder, open grate area, A and drain dimensions corresponds to maximal hydraulic capacity requirement, grating with appropriate load class, no void space between floor and frame, grating with minimum thickness of 5mm, removable silt basket, appropriate opening area to capture solid waste, no dead space inside the silt basket, removable water trap with water seal height minimally 50 mm, dry sump and stainless steel gully body, vertical pipe, suitable pipe size and with backflow. In a nutshell, the minimum components for a hygienic drain design should contains grating, frame, silt basket, foul air trap, gully body and transfer piping.

5.4 Research Contribution

The drain model designed through analysis of the hydraulic load of Factory Y can be a reference for owner of Factory Y in case of retrofit in the future. Besides, the checklist developed serves as a guideline for other small and medium enterprise of meat, poultry industry as these industry generates large amount of waste water per day. Hence, it is important for the wastewater to be drained quickly and effectively.With a standard food processing drainage model, the production environment will be able to meet the criteria to secure the MesTI, Good Veterinary Hygiene Practice (GVHP) certificate. Hygiene of food is important for food industry to maintain the image of industry and prevent theoutbreak of foodborne diseases.

5.5 Research Limitation and Future Work Recommendation

While performing this research project, there were some limitation encountered. One of the limitations is time constraints. The project was halted for more than 1 months due to the outbreak of Covid-19 in March, April, May. Analysis and lab work only start after June.In addition, there is only little reference of drain model, calculation about the point gully in meat processing area in Malaysia and globally.As for recommendation, for future testing of model designed, the engineering software such as ANSYS can be used to simulate the flow in the production area towards the drain model and determine the hydraulic efficiency of the designed drain.

Besides, it is also encouraged to understand more on the effect of design and installation on other types of drainage model such as channel type. Thus, more research is necessary to support the findings and convince the society.

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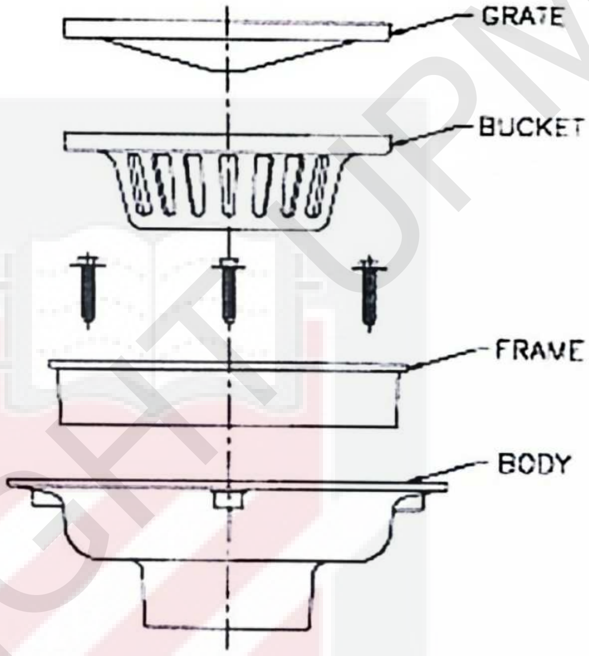
APPENDICES

Appendix 1: Design checklist for drain 2 at Factory Y

<table>
<tr><th colspan="6">GULLY'S DESIGN CHECKLIST IN WET AREAS FOR MEAT PRODUCTS</th></tr>
<tr><td colspan="2">Minimum major components checklist.</td><td colspan="4">Illustrations</td></tr>
<tr><td colspan="2">Tick X for available components in the design.

A. Grating — X
B. Frame —
C. Silt basket —
D. Foul air trap —
E. Gully body —
F. Piping —</td><td colspan="4">
</td></tr>
<tr><td colspan="2">General criteria</td><td>Yes</td><td>No</td><td>NA</td><td>Remarks</td></tr>
<tr><td>1</td><td>All minimum components are available in the drain design</td><td></td><td>X</td><td></td><td></td></tr>
<tr><td>2</td><td>All components are made of stainless steel AISI304
*If use chlorine disinfection, AISI316 is recommended</td><td>X</td><td></td><td></td><td></td></tr>
</table>

3		Full pickle passivation for the drainage components		X		Not passivated
Features of the components						
Part A : Grating			**Yes**	**No**	**NA**	**Remarks**
4	A1	Surface roughness average for the drain, $R_a < 0.8 \mu m$ **OR** all surfaces comply to the following designs: • Continuous welding of joints • No crevices and dead-end • Rounded or radiuses corners (minimum radii of 3 mm)		X		Stainless steel of drain 2 at Factory Y is observed to have some pit, and is corroded
5	A2	Non-slip grating		X		

6	A3	Removable grating with ladder grating or cast grating with rounded corners and no weld		X		The grating of Drain 2 are difficult to be removed since it is located under flaking machines which cause the drain cannot be cleaned effectively.

7	A4	Open grate area (A) and drain dimensions corresponds to maximal hydraulic capacity requirement + allowance: $A = \frac{Q}{0.6 \times \sqrt{2gh}}$ Q = maximal hydraulic capacity requirement + 100% allowance X L/s Cd = 0.6 $g = 9.81 m/s^2$ h = 0.005 m (maximal head allowed) • Example when Q = 0.0012 m^3/s $A = \frac{0.0012\ m^3}{0.6 \cdot \sqrt{2 \cdot 9.81 \cdot 0.005}}$ $= 6.39 \times 10^{-3}\ m^2$ $= 6390\ mm^2$		X		The current opening area of drain 2 (6361 mm^2) is slightly lower than the minimum area required(6390 mm^2)

8	A5	Grating should have load class according to loading classification: • Light duty : Grates test under 900 kg • Medium duty: Grates test 900-2250 kg • Heavy duty: Grates test 2250-3375 kg Extra heavy duty: Grates test 3375-4500 kg	X			The designed drain have medium load class.
Part B : Frame			**Yes**	**No**	**NA**	**Remarks**
9	B1	No void space between floor and frame e.g. U-edge profile that embedded deep inside the concrete			X	Drain 2 has no frame
10	B2	Minimal thickness of 5mm			X	
Part C: Silt basket			**Yes**	**No**	**NA**	**Remarks**
11	C1	Removable silt basket for easy cleaning			X	Drain 2 has no silt basket

12	C2	Appropriate area opening to capture solid soil but not affect the hydraulic capacity			X	
13	C3	No dead space, crevices and rough surfaces			X	
Part D : Foul air trap			**Yes**	**No**	**NA**	**Remarks**
14	D1	Removable water trap with water seal height minimally 50 mm			X	Drain 2 has no foul air trap
Part E : Gully body			**Yes**	**No**	**NA**	**Remarks**
15	E1	Surface roughness average for the drain, $R_a < 0.8 \mu m$ **OR** all surfaces comply to the following designs: • Continuous welding of joints • No crevices and dead-end Rounded or radiuses corners (minimum radii of 3 mm)		X		The gully body of drain 2 is made of mortar, surface is rough with crevices and dead spaces

116	E2	Dry sump to avoid accumulation of water		X		The inside of the gully body is always wet and has foul smell, with waste water accumulation
Part F : Piping to sewer			**Yes**	**No**	**NA**	**Remarks**
117	F1	Vertical spigot outlet is recommended with 45° swept bend		X		The outlet piping is also made of mortar and is horizontal
118	F2	Back flow prevention		X		Not at Drain 2 but located at the sewer

19	F3	The size of the piping can be determined through equation below, nominal pipe size (NPS) table as ASME B36.19 and design stress table for stainless steel pipe as attached in appendix. $Q_C = v \times (\pi \cdot \frac{D_i^2}{4})$ $Q_C = hydraulic\_capacity$ $v = velocity\_of\_flow@opening$ $D_i = inner\_diameter$ $Schedule\_number = 1000 \times \frac{P}{S}$ $P = design\_pressure$ $S = design\_stress$ $D_o = D_i + 2 \times t$ $t = thickness\_of\_pipe$			X	
		Total	Total only 12 out of 19 are applicable. Only 2 out of 12 criteria for drain 2 at factory Y are met (16.67%).			

Appendix 2: Installation checklist for drain 2 at Factory Y

Installation checklist for hydraulic efficient gully				
No	Detail	Yes	No	Remarks
1	Proximity to the wastewater source distance at most 5m	√		
2	Location of drainage is accessible for cleaning, inspection and maintenance		√	Drain 2 is installed under the machinery, the drainage is difficult to clean
3	Location when possible avoids traffic. If unavoidable, the drain must resist applied load and turning stress	√		Drain 2 is not accessible for traffic.
4	Gully's design fit to be installed in the flooring. E.g. Square gully for tiles and resin flooring, rounded gully for resin and vinyl flooring		√	
5	Gullies are secured in the floor with anchor		√	No anchor
6	Frame has to be installed below the final floor layer		√	The frame structure is not available, only the grate is installed.

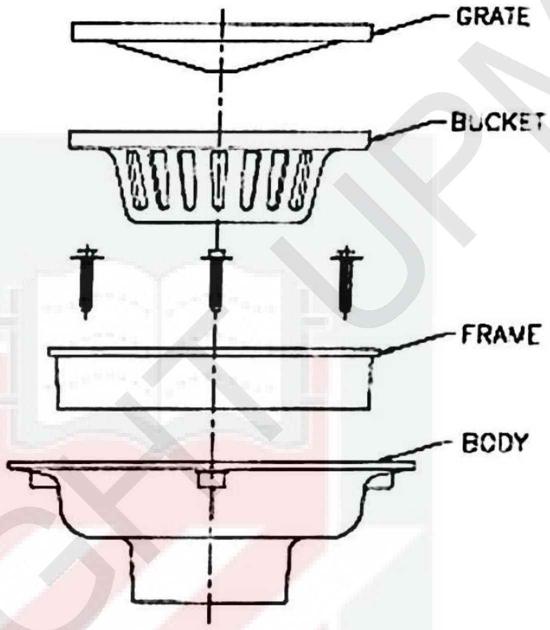
7	Flooring material around the frame is increased and use of appropriate sealant at floor-drain-interface		√	Both frame and sealant are not installed.
8	Drain receive falls from 4 sides with floor sloping of 1.5 -2 %		√	Drain 2 is found to receive 2 falls only. The current floor sloping at both directions are 0.45% and 2.18% respectively and do not meet the required minimum slope.
9	Square gully must be installed with shaped edge profile • 1.5 mm steel thickness • Fillant is of waterproof material • Frame height is deeper than flooring layer (10-20 mm)		√	Structure for edge and frame are not installed.
10	In multiple-storey building, where the drain is located above ground level • Use of membrane to prevent possible water penetration to the lower ceiling			Not applicable

	• Drainage piping must be double-walled when penetrate into hygienic area and made from non-flammable material.			
11	Drainage layout allows wastewater to flow direction from high risk to low risk are	√		Effluent flow from high risk (packing area) to low risk (wet production) due to overall floor sloping.
12	Piping layout with swept tees and soft bend to allow wastewater moving towards cleaning well that is positioned outside hygienic area.		√	Drain 2 did not has proper piping and the wastewater is directed through horizontal outlet towards man sewer. Thus, swept tees and soft bend are not applicable.
Total "Yes" and "No" out of 12 criteria				Only 11 criteria are applicable. 3/11 criteria are met (27.27%).

Appendix 3: Design checklist for new designed drain

GULLY'S DESIGN CHECKLIST IN WET AREAS FOR MEAT PRODUCTS

Minimum major components checklist.			**Illustrations**
Tick X for available components in the design.			
A.	Grating	X	
B.	Frame	X	
C.	Silt basket	X	
D.	Foul air trap	X	
E.	Gully body	X	
F.	Piping	X	



General criteria		**Yes**	**No**	**NA**	**Remarks**
1	All minimum components are available in the drain design	X			
2	All components are made of stainless steel AISI304 *If use chlorine disinfection, AISI316 is recommended	X			
3	Full pickle passivation for the drainage components	X			The drain structure material is passivated with

			Yes	No	NA	Remarks
						nitric acid to remove free iron from the surface hence has long shelf life and resistant to corrosion.
Features of the components						
Part A : Grating			**Yes**	**No**	**NA**	**Remarks**
4	A1	Surface roughness average for the drain, $R_a < 0.8\mu m$ **OR** all surfaces comply to the following designs: • Continuous welding of joints • No crevices and dead-end • Rounded or radiuses corners (minimum radii of 3 mm)	X			
5	A2	Non-slip grating	X			
6	A3	Removable grating with ladder grating or cast grating with rounded	X			The grating can be removed easily for

		corners and no weld				cleaning and inspection
7	A4	Open grate area (A) and drain dimensions corresponds to maximal hydraulic capacity requirement + allowance: $A = \frac{Q}{0.6 \times \sqrt{2gh}}$ Q = maximal hydraulic capacity requirement + 100% allowance X L/s Cd = 0.6 $g = 9.81 m/s^2$ h = 0.005 m (maximal head allowed) • Example when Q = 0.0012 m^3/s $A = \frac{0.0012 \ m^3}{0.6 \cdot \sqrt{2 \cdot 9.81 \cdot 0.005}}$ $= 6.39 \times 10^{-3} \ m^2$ $= 6390 \ mm^2$	X			The designed drain open grate area is greater than the maximal hydraulic capacity requirement for the gully. The open grate area of designed drain is = $A = (200) \times (200) mm$ $- 200mm(20mm)(8)$ $= 8000 mm^2$
8	A5	Grating should have load class according to loading classification:	X			The designed drain have medium load

		• Light duty : Grates test under 900 kg • Medium duty: Grates test 900-2250 kg • Heavy duty: Grates test 2250-3375 kg Extra heavy duty: Grates test 3375-4500 kg				class
Part B : Frame			**Yes**	**No**	**NA**	**Remarks**
9	B1	No void space between floor and frame e.g. U-edge profile that embedded deep inside the concrete	X			
10	B2	Minimal thickness of 5mm	X			The frame thickness is 5mm
Part C: Silt basket			**Yes**	**No**	**NA**	**Remarks**
11	C1	Removable silt basket for easy cleaning	X			
12	C2	Appropriate area opening to capture solid soil but not affect the hydraulic capacity	X			
13	C3	No dead space, crevices and rough	X			The silt basket has

		surfaces				minimum radius of 3mm at the corner
Part D : Foul air trap			**Yes**	**No**	**NA**	**Remarks**
14	D1	Removable water trap with water seal height minimally 50 mm	X			
Part E : Gully body			**Yes**	**No**	**NA**	**Remarks**
15	E1	Surface roughness average for the drain, $R_a < 0.8\mu m$ **OR** all surfaces comply to the following designs: • Continuous welding of joints • No crevices and dead-end Rounded or radiuses corners (minimum radii of 3 mm)	X			
16	E2	Dry sump to avoid accumulation of water	X			The gully body has a vertical connection with outlet piping which transfer the waste water to sewage system

Part F : Piping to sewer			Yes	No	NA	Remarks
17	F1	Vertical spigot outlet is recommended with 45° swept bend	X			
18	F2	Back flow prevention	X			
19	F3	The size of the piping can be determined through equation below, nominal pipe size (NPS) table as ASME B36.19 and design stress table for stainless steel pipe as attached in appendix. $Q_C = v \times (\pi \cdot \frac{D_i^2}{4})$ $Q_C = hydraulic\_capacity$ $v = velocity\_of\_flow@opening$ $D_i = inner\_diameter$ $Schedule\_number = 1000 \times \frac{P}{S}$ $P = design\_pressure$ $S = design\_stress$ $D_O = D_i + 2 \times t$ $t = thickness\_of\_pipe$	X			
		Total	All criteria are applicable. All 19/19 criteria are met with 100%.			

Appendix 4: Installation checklist for the new drain

Installation checklist for hydraulic efficient gully				
No	Detail	Yes	No	Remarks
1	Proximity to the wastewater source distance at most 5m	√		
2	Location of drainage is accessible for cleaning, inspection and maintenance	√		The new drain is installed at 2m away from machinery instead of directly under the machinery as drain 2 of Factory Y
3	Location when possible avoids traffic. If unavoidable, the drain must resist applied load and turning stress	√		The new drain is installed at area that can avoids traffic.
4	Gully's design fit to be installed in the flooring. E.g. Square gully for tiles and resin flooring, rounded gully for resin and vinyl flooring	√		The designed gully is a round gully body with square frame, which is suitable for concrete flooring.

5	Gullies are secured in the floor with anchor	√		The frame is fixed and anchored to the ground with two 2mm screw lock
6	Frame has to be installed below the final floor layer	√		Flooring is layered as last step according to the installation manual in Table 2.6.1 after the drain is installed completely.
7	Flooring material around the frame is increased and use of appropriate sealant at floor-drain-interface	√		Flooring is increased after final concreting, followed by filling the gap between the frame and floor with silica gel.
8	Drain receive falls from 4 sides with floor sloping of 1.5 -2 %	√		The designed drain is installed at a place between point A and point B as shown in the floor layout in Figure 4.2.1 so that it receives 4 falls from 4 sides from

				both the burger former and flaker.
9	Square gully must be installed with shaped edge profile • 1.5 mm steel thickness • Fillant is of waterproof material • Frame height is deeper than flooring layer (10-20 mm)	√		The square frame edge is rounded and frame are anchored to the ground with screw lock.
10	In multiple-storey building, where the drain is located above ground level • Use of membrane to prevent possible water penetration to the lower ceiling • Drainage piping must be double-walled when penetrate into hygienic area and made from non-flammable material.			Not applicable

11	Drainage layout allows waste water to flow direction from high risk to low risk area	√		Effluent flow from high risk (packing area) to low risk (wet production) due to overall floor sloping. The drainage piping outlet is also installed according to the flow direction of the factory.
12	Piping layout with swept tees and soft bend to allow wastewater moving towards cleaning well that is positioned outside hygienic area.	√		Horizontal PVC piping with fittings are installed at the outlet of the drain, and sealed properly with minimum gradient.
Total "Yes" and "No" out of 12 criteria				11/11 criteria are met (100%). Only 11 criteria out of 12 criteria are applicable.

Appendix 5: Nominal Pipe Size for stainless steel (ASME B36.19)

ASME/ANSI B36.10/19

The steel pipe data chart below can be used to find pipe sizes, diameters, wall thickness, working pressures and more. The chart is based on ASME/ANSI B 36.10 Welded and Seamless Wrought Steel Pipe and ASME/ANSI B36.19 Stainless Steel Pipe

Regardless of schedule number, pipes of a particular size all have the same outside diameter (not withstanding manufacturing tolerances). As the schedule number increases, the wall thickness increases, and the actual bore is reduced.

For example:

A 4 inches (100 mm) Schedule 40 pipe has an outside diameter of 4.500 inches (114.30 mm), a wall thickness of 0.237 inches (6.02 mm), giving a bore of 4.026 inches (102.26 mm)

A 4 inches (100 mm) Schedule 80 pipe has an outside diameter of 4.500 inches (114.30 mm), a wall thickness of 0.337 inches (8.56 mm), giving a bore of 3.826 inches (97.18 mm)

Pipe Size (inches)	Outside Diameter (inches)	Identification: Steel – Iron Pipe Size	Identification: Steel – Schedule No.	Identification: Stainless Steel Schedule No.	Wall Thickness - t - (inches)	Inside Diameter - d - (inches)	Area of Metal (square inches)	Transverse Internal Area - a - (square inches)	Transverse Internal Area - A - (square feet)	Moment of Inertia - I - (inches^4)	Weight Pipe (pounds per foot)	Weight Water (pounds per foot)	External Surface (square feet per foot of pipe)	Elastic Section Modulus (in^3)
		-	-	10S	.049	.307	.0548	.0740	.00051	.00083	.19	.032	.106	.00437
1/8	0.405	STD	40	40S	.068	.269	.0720	.0568	.00040	.00106	.24	.025	.106	.00523
		XS	80	80S	.095	.215	.0925	.0364	.00025	.00122	.31	.016	.106	.00602
			-	10S	.065	.410	.0970	.1320	.00091	.00279	.33	.057	.141	.01032
1/4	0.540	STD	40	40S	.088	.364	.1250	.1041	.00072	.00331	.42	.045	.141	.01227
		XS	80	80S	.119	.302	.1574	.0716	.00050	.00377	.54	.031	.141	.01395
			-	10S	.065	.545	.1246	.2333	.00162	.00586	.42	.101	.178	.01736
3/8	0.675	STD	40	40S	.091	.493	.1670	.1910	.00133	.00729	.57	.083	.178	.02160
		XS	80	80S	.126	.423	.2173	.1405	.00098	.00862	.74	.061	.178	.02554
			-	5S	.065	.710	.1583	.3959	.00275	.01197	.54	.172	.220	.02849
		-	-	10S	.083	.674	.1974	.3568	.00248	.01431	.67	.155	.220	.03407
1/2	0.840	STD	40	40S	.109	.622	.2503	.3040	.00211	.01709	.85	.132	.220	.04069
		XS	80	80S	.147	.546	.3200	.2340	.00163	.02008	1.09	.102	.220	.04780
		-	160	-	.187	.466	.3836	.1706	.00118	.02212	1.31	.074	.220	.05267
		XXS	-	-	.294	.252	.5043	.050	.00035	.02424	1.71	.022	.220	.05772

Pipe Size (inches)	Outside Diameter (inches)	Identification			Wall Thickness - t - (inches)	Inside Diameter - d - (inches)	Area of Metal (square inches)	Transverse Internal Area		Moment of Inertia - - I - (inches⁴)	Weight Pipe (pounds per foot)	Weight Water (pounds per foot)	External Surface (square feet per foot of pipe)	Elastic Section Modulus (in^3)
		Steel		Stainless Steel Schedule No.				- a - (square inches)	- A - (square feet)					
		Iron Pipe Size	Schedule No.											
3/4	1.050	-	-	5S	.065	.920	.2011	.6648	.00462	.02450	.69	.288	.275	.04667
		-	-	10S	.083	.884	.2521	.6138	.00426	.02969	.86	.266	.275	.05655
		STD	40	40S	.113	.824	.3326	.5330	.00371	.03704	1.13	.231	.275	.07055
		XS	80	80S	.154	.742	.4335	.4330	.00300	.04479	1.47	.188	.275	.08531
		-	160	-	.219	.612	.5698	.2961	.00206	.05269	1.94	.128	.275	.10036
		XXS	-	-	.308	.434	.7180	.148	.00103	.05792	2.44	.064	.275	.11032
1	1.315	-	-	5S	.065	1.185	.2553	1.1029	.00766	.04999	.87	.478	.344	.07603
		-	-	10S	.109	1.097	.4130	.9452	.00656	.07569	1.40	.409	.344	.11512
		STD	40	40S	.133	1.049	.4939	.8640	.00600	.08734	1.68	.375	.344	.1328
		XS	80	80S	.179	.957	.6388	.7190	.00499	.1056	2.17	.312	.344	.1606
		-	160	-	.250	.815	.8365	.5217	.00362	.1251	2.84	.230	.344	.1903
		XXS	-	-	.358	.599	1.0760	.282	.00196	.1405	3.66	.122	.344	.2136
1 1/4	1.660	-	-	5S	.065	1.530	.3257	1.839	.01277	.1038	1.11	.797	.435	.1250
		-	-	10S	.109	1.442	.4717	1.633	.01134	.1605	1.81	.708	.435	.1934
		STD	40	40S	.140	1.380	.6685	1.495	.01040	.1947	2.27	.649	.435	.2346
		XS	80	80S	.191	1.278	.8815	1.283	.00891	.2418	3.00	.555	.435	.2913
		-	160	-	.250	1.160	1.1070	1.057	.00734	.2839	3.76	.458	.435	.3421
		XXS	-	-	.382	.896	1.534	.630	.00438	.3411	5.21	.273	.435	.4110
1 1/2	1.900	-	-	5S	.065	1.770	.3747	2.461	.01709	.1579	1.28	1.066	.497	.1662
		-	-	10S	.109	1.682	.6133	2.222	.01543	.2468	2.09	.963	.497	.2598
		STD	40	40S	.145	1.610	.7995	2.036	.01414	.3099	2.72	.882	.497	.3262
		XS	80	80S	.200	1.500	1.068	1.767	.01225	.3912	3.63	.765	.497	.4118
		-	160	-	.281	1.338	1.429	1.406	.00976	.4824	4.86	.608	.497	.5078
		XXS	-	-	.400	1.100	1.885	.950	.00660	.5678	6.41	.42	.497	.5977
2	2.375	-	-	5S	.065	2.245	.4717	3.958	.02749	.3149	1.61	1.72	.622	.2652
		-	-	10S	.109	2.157	.7760	3.654	.02538	.4992	2.64	1.58	.622	.4204
		STD	40	40S	.154	2.067	1.075	3.355	.02330	.6657	3.65	1.45	.622	.5606
		XS	80	80S	.218	1.939	1.477	2.953	.02050	.8679	5.02	1.28	.622	.7309
		-	160	-	.344	1.687	2.190	2.241	.01556	1.162	7.46	.97	.622	.979
		XXS	-	-	.436	1.503	2.656	1.774	.01232	1.311	9.03	.77	.622	1.104

Pipe Size (inches)	Outside Diameter (inches)	Identification: Steel – Iron Pipe Size	Identification: Steel – Schedule No.	Identification: Stainless Steel Schedule No.	Wall Thickness - t (inches)	Inside Diameter - d (inches)	Area of Metal (square inches)	Transverse Internal Area -a- (square inches)	Transverse Internal Area -A- (square feet)	Moment of Inertia - I - (inches⁴)	Weight Pipe (pounds per foot)	Weight Water (pounds per foot)	External Surface (square feet per foot of pipe)	Elastic Section Modulus (in³)
2 1/2	2.875	.	.	5S	.083	2.709	.7280	5.764	.04002	.7100	2.48	2.50	.753	.4939
		.	.	10S	.120	2.635	1.039	5.453	.03787	.9873	3.53	2.36	.753	.6868
		STD	40	40S	.203	2.469	1.704	4.788	.03322	1.530	5.79	2.07	.753	1.064
		XS	80	80S	.276	2.323	2.254	4.238	.02942	1.924	7.66	1.87	.753	1.339
		.	160	.	.375	2.125	2.945	3.546	.02463	2.353	10.01	1.54	.753	1.638
		XXS	.	.	.552	1.771	4.028	2.464	.01710	2.871	13.69	1.07	.753	1.997
3	3.500	.	.	5S	.083	3.334	.8910	8.730	.06063	1.301	3.03	3.78	.916	.7435
		.	.	10S	.120	3.260	1.274	8.347	.05796	1.822	4.33	3.62	.916	1.041
		STD	40	40S	.216	3.068	2.228	7.393	.05130	3.017	7.58	3.20	.916	1.724
		XS	80	80S	.300	2.900	3.016	6.605	.04587	3.894	10.25	2.6	.916	2.225
		.	160	.	.438	2.624	4.205	5.408	.03755	5.032	14.32	2.35	.916	2.876
		XXS			.600	2.300	5.466	4.155	.02885	5.993	18.58	1.80	.916	3.424
3 1/2	4.000	.	.	5S	.083	3.834	1.021	11.545	.08017	1.960	3.48	5.00	1.047	.9799
		.	.	10S	.120	3.760	1.463	11.104	.07711	2.755	4.97	4.81	1.047	1.378
		STD	40	40S	.226	3.548	2.680	9.886	.06870	4.788	9.11	4.29	1.047	2.394
		XS	80	80S	.318	3.364	3.678	8.888	.06170	6.280	12.50	3.84	1.047	3.140
4	4.500	.	.	5S	.083	4.334	1.152	14.75	.10245	2.810	3.92	6.39	1.178	1.249
		.	.	10S	.120	4.260	1.651	14.25	.09898	3.963	5.61	6.18	1.178	1.761
		STD	40	40S	.237	4.026	3.174	12.73	.08840	7.233	10.79	5.50	1.178	3.214
		XS	80	80S	.337	3.826	4.407	11.50	.07986	9.610	14.98	4.98	1.178	4.271
		.	120	.	.438	3.624	5.595	10.31	.0716	11.65	19.0	4.47	1.178	5.178
		.	160	.	.531	3.438	6.621	9.28	.0645	13.27	22.51	4.02	1.178	5.898
		XXS	.	.	.674	3.152	8.101	7.80	.0542	15.28	27.54	3.38	1.178	6.791
5	5.563	.	.	5S	.109	5.345	1.868	22.44	.1558	6.947	6.36	9.72	1.456	2.498
		.	.	10S	.134	5.295	2.285	22.02	.1529	8.425	7.77	9.54	1.456	3.029
		STD	40	40S	.258	5.047	4.300	20.01	.1390	15.16	14.62	8.67	1.456	5.451
		XS	80	80S	.375	4.813	6.112	18.19	.1263	20.67	20.78	7.88	1.456	7.431
		.	120	.	.500	4.563	7.953	16.35	.1136	25.73	27.04	7.09	1.456	9.250
		.	160	.	.625	4.313	9.696	14.61	.1015	30.03	32.96	6.33	1.456	10.796
		XXS	.	.	.750	4.063	11.340	12.97	.0901	33.63	38.55	5.61	1.456	12.090

Pipe Size (inches)	Outside Diameter (inches)	Identification: Steel – Iron Pipe Size	Identification: Steel – Schedule No.	Identification: Stainless Steel Schedule No.	Wall Thickness - t (inches)	Inside Diameter - d (inches)	Area of Metal (square inches)	Transverse Internal Area -a- (square inches)	Transverse Internal Area -A- (square feet)	Moment of Inertia - I - (inches⁴)	Weight Pipe (pounds per foot)	Weight Water (pounds per foot)	External Surface (square feet per foot of pipe)	Elastic Section Modulus (in³)
6	6.625	.	.	5S	.109	6.407	2.231	32.24	.2239	11.85	7.60	13.97	1.734	3.576
		.	.	10S	.134	6.357	2.733	31.74	.2204	14.40	9.29	13.75	1.734	4.346
		STD	40	40S	.280	6.065	5.581	28.89	.2006	28.14	18.97	12.51	1.734	8.496
		XS	80	80S	.432	5.761	8.405	26.07	.1810	40.49	28.57	11.29	1.734	12.22
		.	120		.562	5.501	10.70	23.77	.1650	49.61	36.39	10.30	1.734	14.98
		.	160	.	.718	5.187	13.32	21.15	.1469	58.97	45.35	9.16	1.734	17.81
		XXS	.		.864	4.897	15.64	18.84	.1308	66.33	53.16	8.16	1.734	20.02
8	8.625	.	.	5S	.109	8.407	2.916	55.51	.3855	26.44	9.93	24.06	2.258	8.131
		.	.	10S	.148	8.329	3.941	54.48	.3784	35.41	13.40	23.61	2.258	8.212
		.	20	.	.250	8.125	6.57	51.85	.3601	57.72	22.36	22.47	2.258	13.39
		.	30	.	.277	8.071	7.26	51.16	.3553	63.35	24.70	22.17	2.258	14.69
		STD	40	40S	.322	7.981	8.40	50.03	.3474	72.49	28.55	21.70	2.258	16.81
		.	60	.	.406	7.813	10.48	47.94	.3329	88.73	35.64	20.77	2.258	20.58
		XS	80	80S	.500	7.625	12.76	45.66	.3171	105.7	43.39	19.78	2.258	24.51
		.	100	.	.594	7.437	14.96	43.46	.3018	121.3	50.95	18.83	2.258	28.14
		.	120	.	.719	7.187	17.84	40.59	.2819	140.5	60.71	17.59	2.258	32.58
		.	140	.	.812	7.001	19.93	38.50	.2673	153.7	67.76	16.68	2.258	35.65
		XXS	.		.875	6.875	21.30	37.12	.2578	162.0	72.42	16.10	2.258	37.56
			160	.	.906	6.813	21.97	36.46	.2532	165.9	74.69	15.80	2.258	38.48
10	10.750	.	.	5S	.134	10.482	4.36	86.29	.5992	63.0	15.19	37.39	2.814	11.71
		.	.	10S	.165	10.420	5.49	85.28	.5922	76.9	18.65	36.95	2.814	14.30
			20	.	.250	10.250	8.24	82.52	.5731	113.7	28.04	35.76	2.814	21.15
			30	.	.307	10.136	10.07	80.69	.5603	137.4	34.24	34.96	2.814	25.57
		STD	40	40S	.365	10.020	11.90	78.86	.5475	160.7	40.48	34.20	2.814	29.90
		XS	60	80S	.500	9.750	16.10	74.66	.5185	212.0	54.74	32.35	2.814	39.43
			80		.594	9.562	18.92	71.84	.4989	244.8	64.43	31.13	2.814	45.54
			100	.	.719	9.312	22.63	68.13	.4732	286.1	77.03	29.53	2.814	53.22
		.	120	.	.844	9.062	26.24	64.53	.4481	324.2	89.29	27.96	2.814	60.32
			140	.	1.000	8.750	30.63	60.13	.4176	367.8	104.13	26.06	2.814	68.43
		.	160		1.125	8.500	34.02	56.75	.3941	399.3	115.64	24.59	2.814	74.29

Appendix 6: Table of Maximum allowable stress for stainless steel pipe AISI304

Table HF-300.1
Maximum Allowable Stress Values for Ferrous Materials, ksi
(Multiply by 1,000 to Obtain psi) (Cont'd)

Spec. No.	Grade	Nominal Composition	P-No.	Group No.	External Pressure Chart	Spec. Min. Tensile Strength, ksi	Spec. Min. Yield Strength, ksi	Note(s)	Maximum Allowable Stress Value, ksi: Up to 100°F	150	200	250	300	350	400	450	500
Plate																	
Alloy Steel (Cont'd)																	
	S43932	18Cr-Ti-Co	7	2	CS-2	65.0	30.0	(12)(13)(15)	13.0	13.0	13.0	12.8	12.6	12.4	12.2	12.1	12.0
	904L	44Fe-25Ni-21Cr-Mo	45	...	NFN-9	71.0	31.0	...	14.2	14.2	14.2	13.9	13.6	13.3	13.1	12.9	12.7
Tube																	
Alloy Steel																	
SA-213	TP304	Smls. 18Cr-8Ni	8	1	HA-1	75.0	30.0	(17)(18)	15.0	15.0	14.2	13.6	13.2	13.0	12.8	12.7	12.7
SA-789	S32101	Smls 21Cr-5Mn-1.5Ni-Cu-N	10H	1	HA-5	101	77.0	(25)	20.2	20.2	20.2	19.8	19.3	18.8	18.6	18.5	18.5
	S32101	Smls 21Cr-5Mn-1.5Ni-Cu-N	10H	1	HA-5	94.0	65.0	(26)	18.8	18.8	18.8	18.5	17.9	17.5	17.3	17.2	17.2
	S32101	Wld 21Cr-5Mn-1.5Ni-Cu-N	10H	1	HA-5	101	77.0	(25)	17.2	17.2	17.2	16.9	16.4	16.0	15.8	15.7	15.7
	S32101	Wld 21Cr-5Mn-1.5Ni-Cu-N	10H	1	HA-5	94.0	65.0	(26)	16.0	16.0	16.0	15.7	15.2	14.9	14.7	14.6	14.6
SA-268	S44400	18Cr-2Mo	7	2	CS-2	60.0	40.0	(13)	12.0	12.0	12.0	11.8	11.6	11.5	11.4	11.2	11.1
	TP439	18Cr-Ti	7	2	CS-2	60.0	30.0	(12)(13)	12.0	12.0	12.0	11.8	11.6	11.4	11.3	11.2	11.0
	S44735	Smls. 29Cr-4Mo	10J	1	HA-6	75.0	60.0	(19)	15.0	15.0	15.0	14.7	14.5	14.4	14.4	14.4	14.4
	S44735	Wld. 29Cr-4Mo	10J	1	HA-6	75.0	60.0	(7)(19)	12.8	12.8	12.7	12.5	12.3	12.2	12.2	12.2	12.2
Pipe																	
Alloy Steel																	
SA-312	TP304	Smls. 18Cr-8Ni	8	1	HA-1	75.0	30.0	(18)(12)	15.0	15.0	14.2	13.6	13.2	13.0	12.8	12.7	12.7
	TP304L	Smls. 18Cr-8Ni	8	1	HA-3	70.0	25.0	(18)(12)	14.0	13.9	13.2	12.7	12.2	12.0	11.7	11.3	10.9
	TP316	Smls. 16Cr-12Ni-2Mo	8	1	HA-2	75.0	30.0	(18)(12)	15.0	15.0	15.0	14.8	14.6	14.4	14.3	13.8	13.3
	TP316L	Smls. 16Cr-12Ni-2Mo	8	1	HA-4	70.0	25.0	(18)(12)	14.0	14.0	13.6	13.1	12.7	12.1	11.7	11.3	10.9
	TP304	Wld. 18Cr-8Ni	8	1	HA-1	75.0	30.0	(7)(18)(12)	12.8	12.7	12.1	11.6	11.3	11.0	10.9	10.8	10.8

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Table HF-300.1
Maximum Allowable Stress Values for Ferrous Materials, ksi
(Multiply by 1,000 to Obtain psi) (Cont'd)

Spec. No.	Grade	Nominal Composition	P-No.	Group No.	External Pressure Chart	Spec. Min. Tensile Strength, ksi	Spec. Min. Yield Strength, ksi	Note(s)	Maximum Allowable Stress Value, ksi: Up to 100°F	150	200	250	300	350	400	450	500
Pipe																	
Alloy Steel (Cont'd)																	
	TP304L	Wld. 18Cr-8Ni	8	1	HA-3	70.0	25.0	(7)(18)(12)	11.9	11.8	11.2	10.8	10.4	10.2	9.9	9.6	9.3
	TP316	Wld. 16Cr-12Ni-2Mo	8	1	HA-2	75.0	30.0	(7)(18)(12)	12.8	12.8	12.8	12.6	12.4	12.3	12.1	11.7	11.3
	TP316L	Wld. 16Cr-12Ni-2Mo	8	1	HA-4	70.0	25.0	(7)(18)(12)	11.9	11.9	11.6	11.2	10.8	10.3	9.9	9.6	9.3
Bar																	
Alloy Steel																	
SA-790	S32101	Smls 21Cr-5Mn-1.5Ni-Cu-N	10H	1	HA-5	101	77.0	(25)	20.2	20.2	20.2	19.8	19.3	18.8	18.6	18.5	18.5
	S32101	Smls 21Cr-5Mn-1.5Ni-Cu-N	10H	1	HA-5	94.0	65.0	(26)	18.8	18.8	18.8	18.5	17.9	17.5	17.3	17.2	17.2
	S32101	Wld 21Cr-5Mn-1.5Ni-Cu-N	10H	1	HA-5	101	77.0	(25)	17.2	17.2	17.2	16.9	16.4	16.0	15.8	15.7	15.7
	S32101	Wld 21Cr-5Mn-1.5Ni-Cu-N	10H	1	HA-5	94.0	65.0	(26)	16.0	16.0	16.0	15.7	15.2	14.9	14.7	14.6	14.6
	316	16Cr-12Ni-2Mo	8	1	HA-2	75.0	30.0	(20) (10)(12) (20)	15.0	15.0	15.0	14.8	14.6	14.4	14.3	13.8	13.3
Forgings																	
Alloy Steel																	
SA-182	F304	18Cr-8Ni	8	1	HA-1	75.0	30.0	(18)(12) (21)	15.0	15.0	14.2	13.6	13.2	13.0	12.8	12.7	12.7
	F304L	18Cr-8Ni	8	1	HA-3	70.0	25.0	(18)(12) (21)	14.0	13.9	13.2	12.7	12.2	12.0	11.7	11.3	10.9
	F316	16Cr-12Ni-2Mo	8	1	HA-2	75.0	30.0	(18)(12) (21)	15.0	15.0	15.0	14.8	14.6	14.4	14.3	13.8	13.3
	F316L	16Cr-12Ni-2Mo	8	1	HA-4	70.0	25.0	(18)(12) (21)	14.0	14.0	13.6	13.1	12.7	12.1	11.7	11.3	10.9
Castings																	
Alloy Steel																	
SA-351	CF8C	18Cr-10Ni-Cb	8	1	...	70.0	...	(9)(12)(22)	11.2	11.2	10.7	10.2	9.8	9.5	9.3	9.1	9.0
	CF3M	16Cr-12Ni-2Mo	8	1	...	70.0	...	(9)(12)(22)	11.2	11.2	11.2	11.0	10.9	10.8	10.8	10.7	10.7