ASSESSMENT OF WATER QUALITY IN HIGH-RISE RESIDENTIAL BUILDING

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SCHOOL OF CIVIL ENGINEERING
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By

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I hereby declare that all corrections and comments made by the supervisor(s)and examiner have been taken into consideration and rectified accordingly.

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Date :

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ABSTRAK

Kajian ini mempunyai dua objektif utama iaitu memantau kualiti air bangunan kediaman bertingkat tinggi di Seberang Perai, Pulau Pinang dan membandingkan hasilnya dengan standard kualiti air minuman di Malaysia dan untuk menganggarkan ketersediaan klorin dan umur airnya di hujung pengguna menggunakan Perisian pemodelan EPANET 2.0. Kajian ini dijalankan untuk mengkaji kualiti air minum rangkaian pengagihan bangunan kediaman bertingkat tinggi di Universiti Sains Malaysia dengan mengumpul sampel dari 2 lokasi berbeza (Desasiswa Tekun dan Utama). Tujuannya adalah untuk menentukan hubungan antara umur air yang disimpan dalam tangki dengan klorin dalam rangkaian pengedaran. Klorin sisa diuji di situ dengan segera manakala pH, kekeruhan dan warna dibawa kembali ke makmal kejuruteraan awam untuk ujian. Keadaan air dan ketersediaan klorin dianggarkan dengan menggunakan pemodelan perisian rangkaian pengagihan air EPANET 2.0. Hasil kajian ini telah menunjukkan bahawa penilaian kualiti air minuman di bangunan kediaman bertingkat tinggi USM dan anggaran menggunakan perisian pemodelan simulasi pengagihan air EPANET 2.0, kajian ini membuktikan bahawa kualiti air yang dibekalkan oleh PBAPP telah memenuhi air minuman Malaysia piawaian kualiti pH air adalah dalam lingkungan 6.5-9.0, kekeruhan yang mengandungi kurang daripada 5 NTU, warna air kurang daripada 15 TCU dan mengandungi kandungan klorin bebas dalam lingkungan 0.2-0.5 mg / l. Nilai klorin yang diramal oleh EPANET 2.0 terletak di dalam julat keputusan di-situ yang diuji

ABSTRACT

This research has two main objectives which are to monitor the water quality of selected high-rise residential building in Seberang Perai, Penang and compare the result with Malaysian drinking water quality standard and to estimate chlorine availability and its water ages at the user's end using EPANET 2.0 modelling software. This study was carried out to examine the drinking water quality of high-rise residential buildings distribution network in Universiti Sains Malaysia by collecting samples from 2 different locations (Desasiswa Tekun and Utama). The aim is to determine the potential relationship between the water age stored in the tanks with the chlorine in the distribution network and test weather can the EPANET 2.0 be use to estimate or predict water quality in small building. The residual chlorine is tested in situ immediately while pH, turbidity and colour are brought back to school of Civil Engineering's laboratory for the test. The water age and chlorine availability were estimated by using water distribution network software modelling EPANET 2.0. The result of this study have shown that assessment of drinking water quality at both USM high-rise residential building and estimation by using EPANET 2.0 water distribution simulation modelling software, this study elucidated that the quality of water supplied are fulfilled the Malaysia drinking water quality standard which is pH of water is within 6.5-9.0, turbidity contain are less than 5 NTU, colour of water is less than 15 TCU and free residual chlorine contain are within 0.2-0.5 mg/l. The value of chlorine contains predicted by the EPANET 2.0 was lies within the range of result in-situ tested

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LIST OF ABBREVIATIONS

BF	Bromoform
CF	Chloroform
DPBs	Disinfection By-Products
DOC	Dissolve Organic Carbon
NOM	Natural Organic Matter
THMs	Trihalomethanes
WHO	World Health Organization
SWTR	Surface Water Treatment Rule

1 INTRODUCTION

1.1 Background

Drinking water or portable is important in human life. Clean and safe water is crucial for daily usage. In Malaysia, chlorination has been used as primary disinfectant to control formation of pathogens in drinking water at water treatment plant (Chang et al., 2010). Chlorine has been widely used as disinfectant due to its low cost and effectiveness in many countries. Chlorine is powerful oxidizing agent will inactive bacteria to prevent the spread of water borne diseases. Chlorine effectively inactivates most of organisms that cause diseases in humans such at 0.2 mg/l chlorine concentration for 3 minutes cause 99.99% reduction of Escherichia coli and at 0.5 mg/l chlorine for 6 minutes reduces 99% Salmonella typhi (Farooq et al., 2008).

Chlorine is not only used as a primary disinfectant in water treatment but is also added to provide a stable disinfectant residual to preserve the quality of the water throughout the distribution network. Water distribution systems play a crucial role in preserving and providing quality water to the public.

Although addition of chlorine in water treatment plant is a common practice, but the dosage may not sufficient, depending on the water age to ensure the constant presence of residual chlorine in the water. Regular testing is essential to ensure that adequate free residual chlorine is still present in the treated water. The maintenance of chlorine residue is needed at all points in distribution system supplied with chlorine as a disinfectant (Munavalli and Kumar, 2003). Maintaining residual chlorine at a certain level in tap water is effective not only in improving sanitary conditions but also in suppressing the regrowth of microorganisms and preventing the formation of biofilms on the internal surface of distribution pipelines (Farooq et al., 2008). Apart from reacting with microbia, chlorine can also react with other compounds contained in the water, thereby forming the so-called disinfection-by-products (DBP) which are suspected to be carcinogenic. Accordingly, the quantity of chlorine added to water have to be minimized to prevent potential DBP formation, but adequate enough for ensuring a sufficient concentration of residual free chlorine instead of combined chlorine during distribution.(Examiner and Marcantoni, 2002)

1.2 Problem Statement

Generally, large buildings such as apartments, multi-family houses, high-rise buildings, and schools opted for a water supply system that involved tanks. After water is produced at the purification plants, the system first stores it in an underground tank, and then pumps the water all the way up to a roof tank, from which water is supplied to each floor. However, that the system presented several problems. Because tap water can be stored in tanks for more than 2-3 days, while flowing through pipes, the chlorine concentration decreases as it decays with time, thus resulting in low or no presence of residual chlorine, giving rise to concerns of bacteria and low turbidity caused by foreign particles. Suspended particles can affect adversely the water quality because they can carry bacteria attached on their surfaces. Roof tanks also pose the risk of deteriorating water quality particularly due to its location. Without proper maintenance, water tanks become vulnerable to foreign particles that undermine water quality as well as to penetrating sunlight that creates a breeding ground for algae, as it is usually placed outdoors on building rooftops.

1.3 Objectives

The objectives in this study are:

1. To monitor the water quality of high-rise residential building in Universiti Sains Malaysia and compare the result with Malaysian drinking water quality standard.
2. To estimate chlorine availability and water ages at the user's end using EPANET 2.0 modelling software

1.4 Scope of Study

This study was carried out to examine the drinking water quality of high-rise residential buildings in University Sains Malaysia (USM), focusing on the chlorine availability by collecting samples from two different locations (Desasiswa Tekun and Utama). The aim is to compare the quality of the drinking water which is pH, turbidity, color and chlorine contain with the Malaysia drinking water quality standard and relate the potential relationship between the water age stored in the tanks with the chlorine residual in the distribution network. Quantification of chlorine residual accordingly to the standard method. The residual chlorine is tested in situ by using DR900 calorimeter. After the sampling was done, the simulation of water distribution at Desasiswa Utama is carried out then estimate the chlorine contain and water ages by using water distribution network software modelling EPANET 2.0.

1.5 Dissertation Outline

In this study, Chapter 1 describe about the importance of study and objectives to assesses the drinking water quality in high-rise residential building and monitored water quality parameter to ensure that the water quality is comply with the quality standard.

Next, chapter 2 explain about literature review of study mostly about chlorine, chlorination, what effecting it and its effect toward human health. Furthermore, here also explaining on the simulation modelling software and the function of EPANET 2.0 modelling software.

For chapter 3 were shows the location for water sampling and the information about the location selected. Besides that, method use and the procedure to determine water quality were explaining in this chapter. Overall, in this chapter explains the flow of experiment from preliminary work until analysis of sample.

In chapter 4, the result of water quality assessment and water network modelling simulation were included in this chapter to discuss and all data collected was presented. Chapter 5 covers about the conclusion based on the results.

2 LITERATURE REVIEW

2.1 High-Rise Residential Building in Penang

For a number of social-economic reasons, Asian countries have higher population density (Niu, 2004). Coupled with the rapid economic development and urbanization in the past two decades, high-rise residential buildings appear over the horizon as rapidly as mushrooms after a rain. As shown in the figure 2.1-1 to 2.1-5, in Pulau Pinang, the unit and sales of the high-rise residential is rapidly increasing every year with 684 (35%) unit sales in 2012, 1024 (58%) in 2013, 1977 (67%) in 2014, 1651 (82%) in 2015, and 4701 (83%) in 2016 (Buku Data Asas Sosio-Ekonomi, 2017). Therefore, the quality of the water in this type of housing is a concern due to drinking water distribution systems in high-rise residential buildings tend to be very long and complex with many branch mains (WHO , 2013).

2012						
DAERAH / *DISTRICT*	JENIS RUMAH / *HOUSING TYPE*	BILANGAN UNIT / *NO. OF UNITS*	KELUASAN (METER PERSEGI) / *SPACE (PER SQUARE METER)*		HARGA (RM) / *PRICE (RM)*	PERATUS JUALAN (%) / *SALES PERCENTAGE (%)*
			TANAH / *LAND*	LANTAI / *FLOOR*		
Barat Daya / *South West*	RUMAH TERES 3 TINGKAT	95	134	244	618,000.00	63.20
	BERKEMBAR 2 TINGKAT	0	0	0	0.00	0.00
	RUMAH SESEBUAH 2 TINGKAT	0	0	0	0.00	0.00
	FLAT KOS RENDAH	165	0	60	42,000.00	0.00
	KONDOMINIUM / APARTMEN	0	0	0	0.00	0.00
Timur Laut / *North East*	BERKEMBAR 2 TINGKAT	0	0	0	-	0.00
	KONDOMINIUM	684	0	127	612,000.00	70.50
Seberang Perai Selatan / *Southern Seberang Perai*	RUMAH TERES 1 TINGKAT	42	127	82	173,000.00	26.2
	RUMAH TERES 2 TINGKAT	230	143	164	318,000-378,000	87.80
	BERKEMBAR 1 TINGKAT	24	297	141	278,000-295,000	50.00
	BERKEMBAR 2 TINGKAT	192	244	192	538,000-570,000	34.90
	TOWN HOUSE	0	0	0	-	0.00
Seberang Perai Tengah / *Central Seberang Perai*	BERKEMBAR 1 TINGKAT	0	0	0	-	0.00
	BERKEMBAR 2 TINGKAT	68	259	217	476,400-680,000	58.8
	BERKEMBAR 3 TINGKAT	16	211	383	683,800.00	81.30
	RUMAH SESEBUAH 2 TINGKAT	43	298	201	570,300.00	27.9
	RUMAH SESEBUAH 3 TINGKAT	28	340	373	672,800-1,188,000	7.10
Seberang Perai Utara / *Northern Seberang Perai*	RUMAH TERES 1 TINGKAT	105	143	102	199,900.00	100.00
	RUMAH TERES 2 TINGKAT	58	143	212	360,900.00	6.90
	RUMAH TERES 3 TINGKAT	48	113	268	758,000.00	0.00
	BERKEMBAR 1 TINGKAT	20	270	175	376,400.00	25.00
	BERKEMBAR 2 TINGKAT	138	281	225	362,000-472,200	68.10
	KONDOMINIUM / APARTMEN	0	0	0	-	0.00
JUMLAH / *TOTAL*		1,956				

Figure 2.1-1: Newly Launched Housing Schemes In 2012
(Sources from Buku Data Asas Sosio-Ekonomi Negeri Pulau Pinang,2017)

2013						
DAERAH / *DISTRICT*	**JENIS RUMAH /** *HOUSING TYPE*	**BILANGAN UNIT /** *NO. OF UNITS*	**KELUASAN (METER PERSEGI) /** *SPACE (PER SQUARE METER)*		**HARGA (RM) /** *PRICE (RM)*	**PERATUS JUALAN (%) /** *SALES PERCENTAGE (%)*
			TANAH / *LAND*	**LANTAI /** *FLOOR*		
Barat Daya / *South West*	RUMAH TERES 3 TINGKAT	19	TD	TD	1,248,160.00	36.80
	BERKEMBAR 2 TINGKAT	0	0	0	0.00	0.00
	RUMAH SESEBUAH 2 TINGKAT	0	0	0	0.00	0.00
	FLAT KOS RENDAH	0	0	0	0.00	0.00
	KONDOMINIUM / APARTMEN	1,024	0	104	560,000.00	80.00
Timur Laut / *North East*	BERKEMBAR 2 TINGKAT	0	0	0	0.00	0.00
	KONDOMINIUM	0	0	0	0.00	0.00
Seberang Perai Selatan / *Southern Seberang Perai*	RUMAH TERES 1 TINGKAT	14	82	127	145,000.00	50.00
	RUMAH TERES 2 TINGKAT	646	167	114	378,000-438,000	80.50
	BERKEMBAR 1 TINGKAT	0	0	0	0.00	0.00
	BERKEMBAR 2 TINGKAT	0	0	0	0.00	0.00
	TOWN HOUSE	0	0	0	0.00	0.00
Seberang Perai Tengah / *Central Seberang Perai*	BERKEMBAR 1 TINGKAT	36	118	297	317,500.00	19.40
	BERKEMBAR 2 TINGKAT	6	187	138	658,000-438,000	0.00
	BERKEMBAR 3 TINGKAT	0	0	0	0.00	0.00
	RUMAH SESEBUAH 2 TINGKAT	0	0	0	0.00	0.00
	RUMAH SESEBUAH 3 TINGKAT	0	0	0	0.00	0.00
Seberang Perai Utara / *Northern Seberang Perai*	RUMAH TERES 1 TINGKAT	0	0	0	0.00	0.00
	RUMAH TERES 2 TINGKAT	0	0	0	0.00	0.00
	RUMAH TERES 3 TINGKAT	0	0	0	0.00	0.00
	BERKEMBAR 1 TINGKAT	0	0	0	0.00	0.00
	BERKEMBAR 2 TINGKAT	0	0	0	0.00	0.00
	KONDOMINIUM / APARTMEN	0	0	0	0.00	0.00
JUMLAH / *TOTAL*		1,745				

Figure 2.1-2: Newly Launched Housing Schemes In 2013
(Sources from Buku Data Asas Sosio-Ekonomi Negeri Pulau Pinang,2017)

2014						
DAERAH / *DISTRICT*	**JENIS RUMAH** / *HOUSING TYPE*	**BILANGAN UNIT** / *NO. OF UNITS*	**KELUASAN (METER PERSEGI)** / *SPACE (PER SQUARE METER)*		**HARGA (RM)** / *PRICE (RM)*	**PERATUS JUALAN (%)** / *SALES PERCENTAGE (%)*
			TANAH / *LAND*	**LANTAI** / *FLOOR*		
Barat Daya / *South West*	RUMAH TERES 3 TINGKAT	5	161,8	264,35	65,000,00	100,00
	BERKEMBAR 2 TINGKAT	10	252	247.63	854,000.00	50.00
	RUMAH SESEBUAH 2 TINGKAT	0	0	0	0,00	0,00
	FLAT KOS RENDAH	0	0	0	0,00	0,00
	KONDOMINIUM / APARTMEN	1,000	0	109.63	584,000.00	47.00
Timur Laut / *North East*	BERKEMBAR 2 TINGKAT	0	0	0	0.00	0.00
	KONDOMINIUM	977	0	120	665,000,00	75,00
Seberang Perai Selatan / *Southern Seberang Perai*	RUMAH TERES 1 TINGKAT	62	186.08	107.95	350,000.00	20.00
	RUMAH TERES 2 TINGKAT	284	111,48	146.64	468,000.00	40.00
	BERKEMBAR 1 TINGKAT	32	268,02	111,48	455,000,00	20,00
	BERKEMBAR 2 TINGKAT	16	255,01	222,96	685,000,00	20,00
	TOWN HOUSE	0	0	0	-	0,00
Seberang Perai Tengah / *Central Seberang Perai*	BERKEMBAR 1 TINGKAT	0	0	0	-	0,00
	BERKEMBAR 2 TINGKAT	4	293,32	307,32	882,420,00	20,00
	BERKEMBAR 3 TINGKAT	64	245	271	889,000,00	40,00
	RUMAH SESEBUAH 2 TINGKAT	98	260	259	598,000,00	40,00
	RUMAH SESEBUAH 3 TINGKAT	57	327	529	1,100,800,00	40,00
Seberang Perai Utara / *Northern Seberang Perai*	RUMAH TERES 1 TINGKAT	224	121	83.61	175,770.00	40.00
	RUMAH TERES 2 TINGKAT	59	162,58	198,32	386,600-550,000	20,00
	RUMAH TERES 3 TINGKAT	33	165,09	292,32	474,550,00	20,00
	BERKEMBAR 1 TINGKAT	0	0	0	-	0.00
	BERKEMBAR 2 TINGKAT	10	235,94	257.18	709,690.00	20,00
	KONDOMINIUM / APARTMEN	0	0	0	-	0,00
JUMLAH / *TOTAL*		2,935				

Figure 2.1-3: Newly Launched Housing Schemes In 2014
(Sources from Buku Data Asas Sosio-Ekonomi Negeri Pulau Pinang,2017)

2015						
DAERAH / *DISTRICT*	**JENIS RUMAH** / *HOUSING TYPE*	**BILANGAN UNIT** / *NO. OF UNITS*	**KELUASAN (METER PERSEGI)** / *SPACE (PER SQUARE METER)*		**HARGA (RM)** / *PRICE (RM)*	**PERATUS JUALAN (%)** / *SALES PERCENTAGE (%)*
			TANAH / *LAND*	**LANTAI** / *FLOOR*		
Barat Daya / *South West*	RUMAH TERES 3 TINGKAT	107	163	275	1,388,800.00	49.50
	BERKEMBAR 2 TINGKAT	0	0	0	0.00	0.00
	RUMAH SESEBUAH 2 TINGKAT	0	0	0	0.00	0.00
	FLAT KOS RENDAH	0	0	0	0.00	0.00
	KONDOMINIUM / APARTMEN	432	0	134	1,150,000.00	40.00
Timur Laut / *North East*	BERKEMBAR 2 TINGKAT	0	0	0	0.00	0.00
	KONDOMINIUM	1,219	0	134	1,150,000.00	40.00
Seberang Perai Selatan / *Southern Seberang Perai*	RUMAH TERES 1 TINGKAT	148	113	82	300,000.00	81.10
	RUMAH TERES 2 TINGKAT	0	0	0	0.00	0.00
	BERKEMBAR 1 TINGKAT	0	0	0	0.00	0.00
	BERKEMBAR 2 TINGKAT	0	0	0	0.00	0.00
	TOWN HOUSE	0	0	0	0.00	0.00
Seberang Perai Tengah / *Central Seberang Perai*	BERKEMBAR 1 TINGKAT	0	0	0	0.00	0.00
	BERKEMBAR 2 TINGKAT	0	0	0	0.00	0.00
	BERKEMBAR 3 TINGKAT	30	238	326	908,000.00	100.00
	RUMAH SESEBUAH 2 TINGKAT	0	0	0	0.00	0.00
	RUMAH SESEBUAH 3 TINGKAT	0	0	0	0.00	0.00
Seberang Perai Utara / *Northern Seberang Perai*	RUMAH TERES 1 TINGKAT	0	0	0	0.00	0.00
	RUMAH TERES 2 TINGKAT	0	0	0	0.00	0.00
	RUMAH TERES 3 TINGKAT	73	119	209	352,000.00	27.40
	BERKEMBAR 1 TINGKAT	0	0	0	0.00	0.00
	BERKEMBAR 2 TINGKAT	0	0	0	0.00	0.00
	KONDOMINIUM / APARTMEN	0	0	0	0.00	0.00
JUMLAH / *TOTAL*		2,009				

Figure 2.1-4: Newly Launched Housing Schemes In 2015
(Sources from Buku Data Asas Sosio-Ekonomi Negeri Pulau Pinang,2017)

2016						
DAERAH / *DISTRICT*	**JENIS RUMAH** / *HOUSING TYPE*	**BILANGAN UNIT** / *NO. OF UNITS*	**KELUASAN (METER PERSEGI)** / *SPACE (PER SQUARE METER)*		**HARGA (RM)** / *PRICE (RM)*	**PERATUS JUALAN (%)** / *SALES PERCENTAGE (%)*
			TANAH / *LAND*	**LANTAI** / *FLOOR*		
Barat Daya / *South West*	RUMAH TERES 3 TINGKAT	7	TD	271	720,000.00	0.00
	BERKEMBAR 2 TINGKAT	14	TD	254	1,730,000 – 3,730,130	42.90
	RUMAH SESEBUAH 2 TINGKAT	0	0	0	0.00	0.00
	FLAT KOS RENDAH	0	0	0	0.00	0.00
	KONDOMINIUM / APARTMEN	853	TD	93	320,000 – 812,500	7.20
Timur Laut / *North East*	FLAT	1,514	TD	102	300,000 – 445,000	0.00
	KONDOMINIUM	1,946	TD	124	400,000 – 1,325,520	11.80
Seberang Perai Selatan / *Southern Seberang Perai*	RUMAH TERES 1 TINGKAT	129	113	90	294,500.00	66.70
	RUMAH TERES 2 TINGKAT	245	143	180	342,000 – 558,000	2.40
	BERKEMBAR 1 TINGKAT	0	0	0	0.00	0.00
	BERKEMBAR 2 TINGKAT	48	250	253	698,000 – 744,000	0.00
	TOWN HOUSE	0	0	0	0.00	0.00
Seberang Perai Tengah / *Central Seberang Perai*	BERKEMBAR 2 TINGKAT	137	129	164	459,000-618,800	27.70
	BERKEMBAR 2.5 TINGKAT	7	164	243	610,000	0.00
	BERKEMBAR 3 TINGKAT	97	147	241	900,000.00	14.40
	RUMAH SESEBUAH 2 TINGKAT	0	0	0	0.00	0.00
	KONDOMINIUM / APARTMEN	276	TD	124	357,000 – 600,000	0.00
Seberang Perai Utara / *Northern Seberang Perai*	RUMAH TERES 1 TINGKAT	0	0	0	0.00	0.00
	RUMAH TERES 2 TINGKAT	0	0	0	0.00	0.00
	RUMAH TERES 3 TINGKAT	8	140	247	760,612.00	100.00
	BERKEMBAR 1 TINGKAT	80	245	128	400,000.00	0.00
	BERKEMBAR 2 TINGKAT	173	284	164	400,000.00	0.00
	KONDOMINIUM / APARTMEN	112	TD	118	337,862.00	100.00
JUMLAH / *TOTAL*		5,646				

Figure 2.1-5: Newly Launched Housing Schemes In 2016
(Sources from Buku Data Asas Sosio-Ekonomi Negeri Pulau Pinang,2017)

2.2 Water quality issues in high-rise building

One of the consequences of the separation of ownership and oversight has been a tendency for water safety in buildings to be overlooked or at best receive limited attention. While community water supplies are generally maintained by water utilities or agencies with particular expertise this is often not the case with water supplies within buildings. Water systems are often managed by general maintenance staff with little training or expertise in managing water quality. Regulatory authorities often establish working relationships and provide oversight of community water supplies but this is more challenging with building managers. As a result, there are many examples where faults within buildings have led to outbreaks of drinking water derived disease. These have included diverse outcomes such as outbreaks of gastrointestinal disease associated with contamination of drinking water by Cryptosporidium and Cyclospora, Legionnaire's disease associated with hot and cold water systems and cooling towers and methaemoglobinemia from boiler fluid contamination of drinking water. Taste and odours have been caused by water stagnation and through backsiphonage from flexible hoses connected to devices such as washing machines and ice machines (WHO,2013).

2.2.1 System design

Many buildings do not have accurate well maintained maps of water systems. This is particularly true for large buildings and can be complicated in buildings that have been renovated or repaired. Pipework belonging to various networks (drinking water, wastewater, recycled water etc.) are often poorly labelled. This can contribute to health risks. In addition, when problems arise instituting responses is often delayed by first having to map the system.

2.2.2 Hazardous event

Buildings represent specific independent environments that can include a wide range of conditions that can contribute to occurrence of hazards. Building water systems are often designed and maintained with limited attention to minimising risks to public health (“WHO, 2013). Hazardous conditions include:

- poor flows and stagnation due to;
    1. poor design including long branch mains and dead ends
    2. intermittent use or extended periods with no use (e.g. floors/wings of hotels with seasonal occupancy, hospital wards, schools)
- poor temperature control including:
    1. elevated temperatures in cold water systems due to proximity of hot water systems and poor insulation
    2. low temperatures in hot water systems due to inadequate heating, poor design, long branch mains and dead ends and poor insulation
- unsuitable materials used in plumbing;
    1. products that leach hazardous chemicals or support microbial growth
    2. materials incompatible with the physical and chemical characteristics of water supplied to the building (leading to increased corrosion or scaling)
- open water storages

- cross-connections with independent water systems (e.g. roof rainwater), fire systems and liquid storages and inadequate backflow prevention from connected water devices (e.g. cooling towers, boilers, washing machines, dishwashers etc)
- poor management, maintenance and repair including
    i. unauthorised connections or repairs
    ii. poor control during renovations and expansion of systems
    iii. poorly labelled pipework (e.g. distinguishing drinking water, wastewater and recycled water systems
    iv. poorly mapped systems (e.g.distribution maps not maintained or updated following modifications)

2.2.3 Microbial hazard

- Faecal contamination

In common with most drinking water supplies ingress of enteric pathogens (bacteria, viruses and protozoa) associated with faecal contamination can be a significant source of hazards. Faecal contamination can enter through community water supplies provided to buildings, independent water supplies and faults in internal plumbing systems (e.g. unroofed water storages, cross-connections with sewage systems or with recycled water systems).

- Growth of environmental organism

Water systems in buildings can be prone to growth of environmental micro-organisms including nuisance species which can cause off-tastes and odours and potentially pathogenic species. Growth of these organisms is often promoted by conditions that support the growth of biofilms including low flows and stagnant water in pipework or end-of pipework devices (e.g. PoU filters) and warm temperatures in cold and hot water networks. Environmental pathogens include Legionella, Mycobacterium spp. And Pseudomonas aeruginosa (“WHO,2013).

2.3 Clean Drinking Water in Malaysia

Water plays an important role in preserve the human health and welfare. Clean drinking water is now recognised as a fundamental right of human beings. Around 780 million people have no access to clean and safe water and about 2,5 billion people does not have sufficient sanitation (Sadef et al., 2015). As a result, around 6–8 million people killed each year by the water related diseases and disasters. Thus, water quality control is a top-priority policy agenda in many parts of the world. World today, the water use in household supplies is commonly defined as domestic water. This water is processed as to be consumed as drinking water and other purposes safely. Water quality and suitability for use are determined by its taste, odour, colour, and concentration of organic and inorganic matters. Contaminants in the water can affect the water quality and consequently the human health.

99% of water supply for Malaysian domestic use are from surface water, while another 1% of the supply from groundwater. Total internal Malaysia water resources are estimated about 580 km3 /year and 30% water withdrawal is for municipal uses (Ab Razak et al., 2015). Water supply sources from surface water and groundwater was treated and distributed to consumers as tap water, bottled mineral water which were used as drinking water. In Malaysia, main sources of drinking are tap water, bottled and drinking water. Water supply from surface water is widely used as drinking water in Malaysia, such as water withdraw from Sungai Langat, Sungai Selangor, Sungai Kinta in West Coast Peninsular Malaysia. Water supply from groundwater is also used as drinking water in a few states of Malaysia such as Kelantan, Terengganu, Pahang, Perlis, Kedah, Sabah, and Sarawak (Ab Razak et al., 2015). Municipal water consisting of untreated surface water and groundwater needs to be treated, before the water is made potable. Treated water from water treatment plant is distributed to consumer as tap water using pipeline system which is provided by water body such as Syarikat Bekalan Air Selangor Sdn. Bhd. (SYABAS) and Syarikat Air Negeri Sembilan Sdn. Bhd. (SAINS) for Selangor and Negeri Sembilan state. Pipeline system used is according to guidelines prepared by National Water Services Commission. There are wide variety of pipes used in Malaysia such as Galvanized Iron (GI), Ductile Iron (DI), Mild Steel (MS), Stainless Steel (SS), asbestos (ABS) and plastics (HDPE and PVC). GI type is the oldest type of pipe that has been used in Malaysia. However, due to low resistant to corrosion, most of states in Malaysia have already replaced this type of pipe with HDPE, SS, DI, and MS pipe (SYABAS,2013)

2.4 Water Quality Testing

The drinking water quality was testing to ensure the continuous supply of clean and safe drinking water for the public health protection. A detailed physical and chemical analysis of drinking water samples need to carry out in different residential and commercial areas (Sadef et al., 2015). The parameters such as pH, turbidity, conductivity, total suspended solids (TSS), total dissolved solids (TDS), and heavy metals such as Cu, Zn, Mg, Fe, Cd, Pb, Cr, As, Hg, and Sn are among the parameters needed to be analyse for each water sample collected during winter and summer periods. The obtained values of each parameter tested need to compare with the standard values set by the World Health Organization (WHO) and local standards such as National Drinking Water Quality Standard (NDWQS). The values of each parameter were found to be within the safe limits set by the WHO and NDWQS (Sadef et al., 2015). Furthermore, it also important to investigate other potential water contaminations such as chemicals and microbial and radiological materials for a longer period of time, including human body fluids, in order to assess the overall water quality.

2.5 Disinfection

Disinfection is an important process to make sure the water is safe to drink. The purpose of disinfection is to destroy microorganism that can cause disease in human body. Disinfection involves the oxidation of organic and inorganic substances and the removal of bacteria and viruses in the drinking water. In Malaysia, chlorination has been widely used as disinfectants in this country until today (Yee et al., 2008). The Surface Water Treatment Rule (SWTR) requires public water systems to disinfect water obtain from surface water supplies or groundwater sources under the influence of surface water. Many types of disinfectant may be used in water treatment process where it is called primary methods of disinfection such as chlorination, chloramines, ozone, and ultraviolet light. Other disinfection methods such as chlorine dioxide, potassium permanganate, and Nano filtration can be used as alternative disinfectant. Since certain forms of chlorine react with organic material naturally present in many water sources to form harmful chemical by-products, the U.S. Environment Protection Agency has proposed maximum levels for these contaminants.

Disinfection by-products	US EPA Maximum Contaminant Level (mg/L)
Bromate	10×10^{-6}
Chloramines	4
Chlorite	1
Haloacetic acids	60
Trihalomethanes (total)	80×10^{-6}

Table 2.5-1: Relevant Standards For Disinfection By-Products In Drinking Water (source from EPA drinking water guidance on disinfection by-products, 2010)

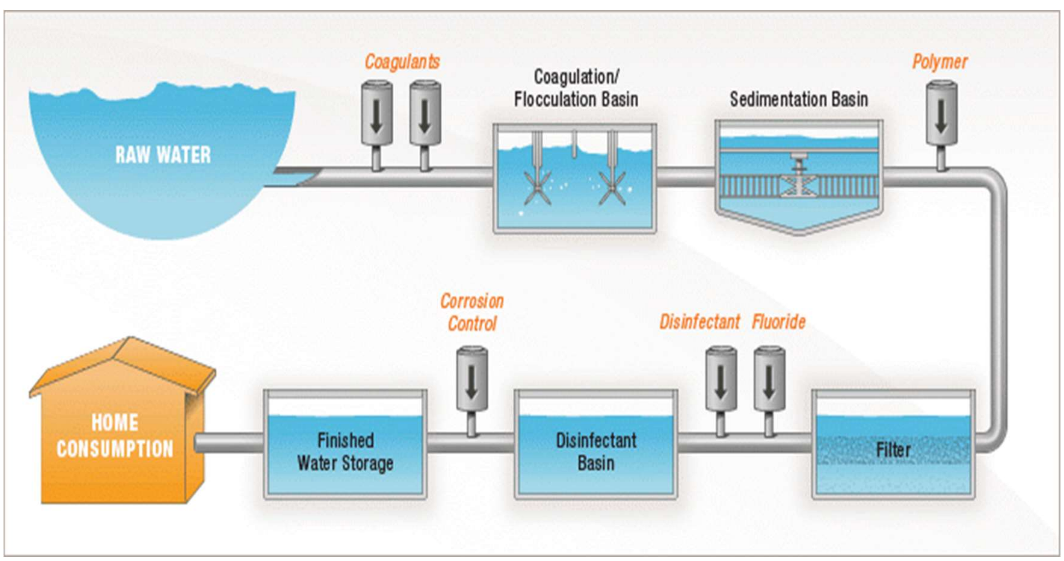

Figure 2.5-1: Main Process of Water Treatment
(Sources from Denverwater, 2019)

2.6 Chlorination

In Malaysia, chlorine was used as primary disinfectant for water disinfection where it can be applied for the deactivation of most pathogenic microorganism and it is relatively cheap (Kanchanamayoon, 2015). Chlorine also can be easily applied, measures and controlled. Chlorine is more efficient than other disinfectant agents such as ozone, chlorine dioxide, and potassium permanganate (Yee et al., 2008). Furthermore, chlorine has been widely used for many applications, such as the deactivation of pathogens in drinking water, swimming pools water and wastewater for more than two hundred (Benami et al., 2015). Chlorine can kill pathogens by breaking the chemical bonds in their molecules. Disinfectants that consist of chlorine compounds can exchange atoms with other compounds, such as enzymes in bacteria and other cells. Additional, chlorine can be added for disinfection in many ways which is pre-chlorination and post-chlorination. When ordinary chlorination is applied, the chlorine is simply added to the water with no prior treatment is necessary. Pre-chlorination and post-chlorination means the additional of chlorine to treated water in one or more points of the distribution system in order to preserve disinfection. Chlorine effectively inactivates most organisms that cause disease in humans at a concentration of 0.2 mg / l of chlorine for 3 minutes, resulting in a 99.99 percent reduction in Escherichia coli and a 6-minute reduction of 99 percent of Salmonella typhi at 0.5 mg / l of chlorine. Addition of chlorine indifferent water treatment plant is a common practice, but it is not sufficient to ensure the safety of water. Regularly testing is necessary to ensure that the treated water still contain adequate free residual chlorine. The maintenance of chlorine residue is needed at all points in distribution system supplied with chlorine as a disinfectant (Farooq et al., 2008).

2.7 Health Concern with Chlorination Water

Chlorine can be toxic to both microorganisms and humans as well. To humans, chlorine caused the symptom such as irritation to the eyes, nasal passages and respiratory system. Chlorine gas need the more concern when handled because it may cause acute health effects and can be fatal at concentrations as low as 1000 ppm, if exposed to. However, regardless to its dangerous thread to human health, it still makes an attractive choice due to it is the least expensive form of chlorine available for water treatment.

However, in drinking water, acute exposure is not a concern as the concentration of chlorine is usually dosage has been designed to meet the standards requirement and usually dosage has been designed to meet the standards requirement and usually safe level for consumption at the user's end. The biggest concern on chlorine consumption effect is the risk of cancer due to long chronic exposure to chlorinated water. This is mainly due to the trihalomethanes and other disinfection by-products (DBP) that from after chlorination process. Trihalomethanes are carcinogens, and have been the topic of concern in chlorinated drinking water. Chlorinated water has been associated with increased risk of bladder, colon and rectal cancer. Although there are concerns about carcinogenic substances in drinking water, the Disease Control Laboratory of Health Canada states that the benefits of chlorinated water in the control of infectious disease outweigh the risks associated with chlorination and would not be sufficient to justify its discontinuation. While in Europe however, chlorination has been discontinued in many communities.

2.8 Effect of Turbidity on Chlorine Efficiency

To define interrelationships between elevated turbidity and the efficiency of chlorination in drinking water, experiments were performed to measure bacterial survival, chlorine demand, and interference with microbiological determinations. (LeChevallier et al., 1981). Experiments were conducted on the surface water supplies for communities which practice chlorination as the only treatment. Therefore, the conclusions of this study apply only to such systems. Results indicated that disinfection efficiency (log10 of the decrease in coliform numbers) was negatively correlated with turbidity and was influenced by season, chlorine demand of the samples, and the initial coliform level. Total organic carbon was found to be associated with turbidity and was shown to interfere with maintenance of a free chlorine residual by creating a chlorine demand. Interference with coliform detection in turbid waters could be demonstrated by the recovery of typical coliforms from apparently negative filters. The incidence of coliform masking in the membrane filter technique was found to increase as the turbidity of the chlorinated samples increased. The magnitude of coliform masking in the membrane filter technique increased from <1 coliform per 100 ml in water samples of <5 nephelometric turbidity units to >1 coliform per 100 ml in water samples of >5 nephelometric turbidity units. Statistical models were developed to predict the impact of turbidity on drinking water quality. The results justify maximum contaminant levels for turbidity in water entering a distribution system as stated in the US National Primary Drinking Water Regulations of the Safe Drinking Water Act.

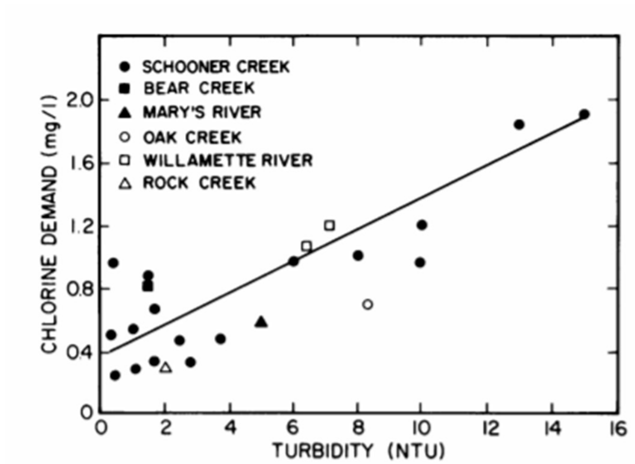

Figure 2.8-1: Relationship between turbidity and chlorine demand in sample collected from six watershed in Oregon, USA

2.9 Water Distribution System Simulation Software (Time Slicing Simulation Method)

Simulation of water distribution networks aims to provide solution of differential algebraic equations used to formulate the mathematical representation of a water distribution system (WDS). Simulation is an invaluable tool in the assessment of WDS response to different operational actions (e.g. valves opening and closing) or control strategies prior to applying the actions to a real water network. The WDS simulation techniques can be classified into:

I. steady-state simulation
II. extended-period simulation
III. transient simulation

Steady-state simulations represent a snapshot of the WDS operation; i.e. demands and pressures at all nodes and flows in all pipes do not vary in time. In real systems, however, the loading conditions and states vary in time. Thus, to evaluate performance of a WDS over a period of time, an extended-period simulation (EPS) is used. This type of analysis considers fluctuations of water level in tanks and demands in discrete time intervals, but with an assumption that in each time interval, the system is in a steady state (Rossman, 2008). The transient simulation provides the most accurate simulation of WDS as it considers naturally unsteady flow conditions incorporating transient analysis. Due to the complexity of this approach it is not yet adopted by many practitioners; mainly limited to specialized applications such as surge studies due to switching control elements. Simulation of a WDS is not an easy task such a solution cannot be obtained analytically. For tree-shaped networks a solution can be obtained by applying the flow continuity equation at all the nodes, but in practice, WDSs are almost never pure tree-shaped networks. The analysis of a water network in a loop configuration presents more challenges. Although, over the last decades a number of methods were proposed. The most noticeable methods include:

a. Hardy Cross method
b. linear theory method
c. Newton-Raphson method
d. linear graph theory method
e. an approach involving optimization methods
f. global gradient method

Implementations of the methods and their hybrids resulted in dozens hydraulic simulators created over the years; e.g. Epanet2, Finesse, H2Onet, WaterCAD. Majority of water networks analysis methods and simulators are based on a time slicing approach such as numerical methods, used in computer simulation of a system characterized by differential equations, require the system to be approximated by discrete quantities. The solution of difference equation is calculated at fixed points in time. This feature of mapping a discrete-time set to a continuous-state set made the discrete-time approach to simulation applicable in many fields, including water networks analysis. Additionally, it is assumed in EPS, that the system is in a steady state between the successive time stamps. But in fact, a real WDS continually adjusts itself in response to changing requirements of the users. This rises an important issue about the model's hydraulic fidelity especially in WDS models with pumps operated on the water level in tanks, as if the time interval is not appropriate the events that actually happened in the real water network might be overlooked. Furthermore, some elements of WDS may cause numerical difficulties (convergence problems) in simulation, due to their inherent non-smooth and discontinuous characteristics. For example, serious convergence problems may be encountered when simulating in Epanet2 a complex and large-scale WDS consisting of hundreds of elements. This is mainly due to the fact that switching events may not happen at the pre-selected time steps and then additional intermediate time steps need to be introduced. Such an approach is used in Epanet2, which introduces the intermediate steps when simulating water network models containing control elements (Rossman, 2008).

2.10 EPANET 2.0 Modelling and Simulation Software

EPANET is a computer program that performs extended period simulation of hydraulic and water quality behaviour within pressurized pipe networks (Rossman, 2008). A network consists of pipes, nodes (pipe junctions), pumps, valves and storage tanks or reservoirs. EPANET tracks the flow of water in each pipe, the pressure at each node, the height of water in each tank, and the concentration of a chemical species throughout the network during a simulation period comprised of multiple time steps. In addition to chemical species, water age and source tracing can also be simulated. EPANET is designed to be a research tool for improving our understanding of the movement and fate of drinking water constituents within distribution systems. It can be used for many different kinds of applications in distribution systems analysis. Sampling program design, hydraulic model calibration, chlorine residual analysis, and consumer exposure assessment are some examples. EPANET can help assess alternative management strategies for improving water quality throughout a system. These can include:

a. altering source utilization within multiple source systems,
b. altering pumping and tank filling/emptying schedules,
c. use of satellite treatment, such as re-chlorination at storage tanks,
d. targeted pipe cleaning and replacement.

Running under Windows, EPANET provides an integrated environment for editing network input data, running hydraulic and water quality simulations, and viewing the results in a variety of formats. These include color-coded network maps, data tables, time series graphs, and contour plots. (Rossman, 2008)

2.10.1 EPANET Water Quality and Hydraulic Modelling Capabilities

Full-featured and accurate hydraulic modelling is a prerequisite for doing effective water quality modelling. EPANET contains a state-of-the-art hydraulic analysis engine that includes the following capabilities:

a. places no limit on the size of the network that can be analysed
b. computes friction head loss using the Hazen-Williams, Darcy-Weisbach, or Chezy-Manning formulas
c. includes minor head losses for bends, fittings, etc.
d. models constant or variable speed pumps
e. computes pumping energy and cost
f. models various types of valves including shutoff, check, pressure regulating, and flow control valves
g. allows storage tanks to have any shape considers multiple demand categories at nodes, each with its own pattern of time variation
h. models pressure-dependent flow issuing from emitters (sprinkler heads)

In addition to hydraulic modelling, EPANET provides the following water quality modelling capabilities:

a) models the movement of a non-reactive tracer material through the network over time
b) models the movement and fate of a reactive material as it grows (e.g., a disinfection by-product) or decays (e.g., chlorine residual) with time
c) models the age of water throughout a network