BOILER WATER REQUIREMENT FOR A SELECTED LOCAL PHARMACEUTICAL FACTORY: A BRIEF CASE STUDY

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Abstract - This case study had been carried out in Ain Medicare Sdn Bhd, a local pharmaceutical factory that is located in Kelantan. In the factory, raw steams from boilers play an important role as heating agent in distillers and autoclaves. The raw steams are produced in the boilers by heating the feed water that is treated with some chemicals in order to make sure the water chemistry in the boiler is below limitation. As the raw steam produced by the boilers exceed the demand, the operating time for each boiler has to be reduced from 19 hours/day to 11.5 hours/day. Material balance on water and steam are required to determine the percentage of steam lost. Besides that, corrosion problem due to vaporization of steam during blowdown has to be minimize by using blowdown vessel. Therefore, blowdown vessel size are suggested to be about 2.5 meter height and 1.8 meter diameter with volume of cooling water is 10.97 m^3 to 11.81 m^3 in a day.

Keywords – boiler, raw steam, autoclaves, distillers, bottom blowdown, blowdown vessel, pharmaceutical factory

I. INTRODUCTION

Ain Medicare Sdn Bhd is a local pharmaceutical factory that produces pharmaceutical products and medical devices such as intravenous solution, small volume injection, anticoagulant injection, and haemodialysis fluid [1]. For most of products, the raw steams from boilers play a major role for water treatment in distiller and for sterilization of products in autoclaves.

A boiler is a closed pressurized vessel used to produce raw steam by applying heat to feed water. In general, there are two types of boiler which are fire-tube boiler used to produce low pressure steam and water-tube boiler used to produce high pressure steam. Fire-tube boiler consists of a series of tubes that are surrounded by feed water. Combustion gases will flow through the tubes and heat the feed water. While in water-tube boiler, the feed water flows inside the series of tubes and the hot combustion gases flow outside the tubes [2]. In this study which had been carried out in a local pharmaceutical company, fire-tube boilers are used to produce raw steam. The operating time for each boiler is 19 hours/day.

Domestic water that is used as the feed water including returned condensate been treated by using few types of chemicals. A few chemicals and feed water will be pumped and mixed in the boiler. The commercial names of these chemicals are Advantage Plus 1400, Amercor 8760, Ametrol 1123 and Biosperse 3001. The functions of these chemicals are to inhibit the formation of hardness-based polymer, corrosion inhibitor, scale inhibitor and bacteria controller, respectively.

Figure 1: Schematic diagram for internal horizontal return tubular fire-tube boiler [2]

The raw steam produced from the boilers will be supply to distillers, autoclaves and heat exchanger. In distiller, the raw steam is used as a heating source of deionized water to produce pure steam that can be converted to water for injection (WFI). WFI is used to produce intravenous solution such as sodium chloride, mannitol, dextrose and so on. In the autoclaves, the raw steam is used to heat the water for sterilization of the products. While in heat exchanger, raw steam is used as a heating agent for haemodialysis fluid as the fluid is classified as medical device, not the pharmaceutical product [1]. According to Latham [23], in pharmaceutical and healthcare industries, the steam from boilers is not suitable to makes products as it contains additives, rust or other undesirable materials. Therefore, the usage of distiller is very important to make sure the products are free from any pathogens.

In the boiler, contaminants can lead to scale formation and corrosion. So, blowdown has to be done in order to discharge the suspended solid from a boiler by some force of steam pressure as well as to control the total dissolved solid (TDS) in the boiler. Source of blowdown water can be classified into two categories, which are surface blowdown and bottom blowdown. Surface blowdown is the removal of suspended solid at the water surface while the bottom blowdown is the removal of sludge that accumulate in the bottom of fire-tube boiler and this way is more effective than the surface blowdown. The blowdown can be done manually and continuously. However, the manual short blowdown will remove sludge more effectively than the continuous blowdown because it is safer during high demand of steam and cause less change in the level of boiler water [30].

In the factory, bottom blowdown is done manually for 45 seconds at every 2 to 3 hours for each operated boilers in order to reduce and control the contaminants of the boiler water. The water will be discharge to the blowdown pit. For the new boiler house that will built in the factory, blowdown vessel is suggested to be used to replace blowdown pit in order to reduce the steam vaporized to atmosphere that will corrode the surrounding equipments.

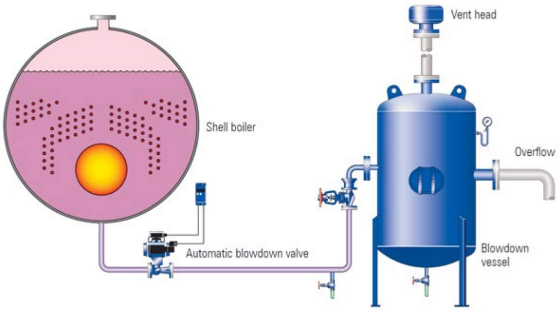

Figure 2: Schematic diagram of fire-tube boiler and blowdown vessel [32]

II. OBJECTIVES

- To study the specification and amount of water required by a boiler and the raw steam produced that will be supplied to autoclaves and distillers for the whole company requirement.
- To make material balance based on raw steam from boiler for daily water usage in Ain Medicare Sdn Bhd.
- To study on the equipments that can be used to reduce the steam released to surrounding as well as to calculate the capacity of blow down discharge and cooling water required.

III. METHODOLOGY

Water balance at the boilers need to be performed in order to determine the volume of feed water required in a day. Then, raw steam material balance at the steam header is done to determine the percentage of steam lost per day, so the new amount of steam needed could be calculated. Thus, the new minimum operation time for the boilers could be determined.

The flowrate of blowdown discharge can be estimated from performance graph provided by Spirax Sarco [29]. By knowing the flowrate of blowdown, the suggested blowdown vessel size can be determine, so that the volume of cooling water that will mix with the hot water from blowdown can be calculated.

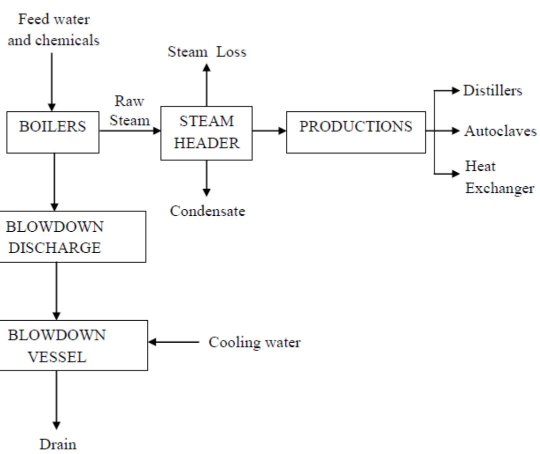

Figure 3: Flowchart of the experimental procedures.

IV. RESULTS AND DISCUSSION

A. Boiler Water Specifications

Boiler failures such as scale formation, overheating and corrosion due to exceed contaminants can be prevented by maintaining the water chemistry in the boiler. A good water chemistry can optimize the efficiency of the boiler, minimize the cost of maintenance and prevent the boilers from exploding due to safety valves failures. In the factory, the water was treated before being used in the boilers. Table 1 below shows the suggested limit of boiler water by Drew Ameroid (M) Sdn Bhd [34] and feed water readings for all three boilers reported in Ain Medicare at 4th May 2016.

Table 1: Recommended limit of boiler water and readings of boiler water in Ain Medicare Sdn Bhd

Characteristic	Recommended Limits by Drew Ameroid (M) Sdn Bhd (2016) [34]	Boilers in Ain Medicare Sdn Bhd		
		No 1	No 2	No 3
pH Value	10.5 – 11.5	11.0	10.5	-
Hydrate Alkalinity ppm $CaCO_3$	200 – 500	300	180	-
Phosphate, ppm PO_4	30 – 50	50	36	-
Sulphite, ppm SO_3	30 – 50	40	24	-
Conductivity, ppm/mmhos	<2000	5760	3620	-
Total hardness, ppm $CaCO_3$	<5.0	1	4	-
Total Iron, ppm Fe	<3.0	0.4	0.4	-

Based on the readings, all the parameters were between the ranges except for hydrate alkalinity, conductivity and sulfite reading. Hydrate alkalinity in Boiler 2 was lower than suggested limitation. Lower hydrate alkalinity meant the hardness was high. Thus, softener that used to filter the feed water before enter the boilers needed to be regenerate and recharge frequently based on regular scheduled basis. Both boilers had high conductivity, which meant that the amount of total dissolved solid (TDS) was high. The higher dissolved solids will increase the risk of carry over the boiler water into the steam, resulting less steam produced. Thus, TDS level in boiler water can be controlled by blowing down the boiler water frequently. For Boiler 2, the sulfite reading was lower than the range recommended. In order to increase the sulfite content, the dosage of chemical that contains sulfite, which was Biosperse 3001 must be increase.

B. Material Balance On Water Of Working Boiler

Figure below shows the process flow diagram for a boiler in the factory.

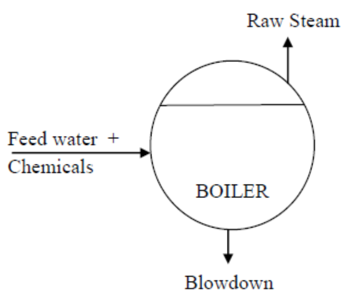

Figure 4: Process flow of a boiler in the factory.

Based on Figure 4, Equation 1 can be produced:

Feed Water = Steam + Blowdown – Chemicals (Eq 1)

Feed water can be calculated by determining the volume of steam, blowdown and chemicals. From the boiler manufacturer's catalog, Mech Mar Sdn Bhd., the steam capacity of each boiler was 3629 kg/hr. Table 2 below shows the summary of steam generated from three boilers that operated 19 hr/day.

Table 2: Summary of steam generated from boilers

Steam capacity of each boiler	3629 kg/hr
Total amount of steam generated	68951 kg/day

However, from previous study, the efficiency of the boilers were assumed to be 70% each due to the fact that a system can never had 100% efficiency value [35]. Table 3 below shows the summary of the actual steam generated after considering the boilers' efficiency:

Table 3: Summary of actual steam generated from boilers

Actual raw steam generated for a boiler	48,265.7 kg/day
Actual total amount of raw steam for three boilers	144,797.1 kg/day
Volume of raw steam produced in a day	$144.8\ m^3$

Hence, the volume of raw steam produced by all boilers in a day was 144.8 m^3, assuming that the raw steam produced was saturated steam at 100°C, and no superheated steam was produced.

The next thing to be determine was the volume of blowdown discharge in a day. The operating pressure inside of each three boilers was 10 bar and the blowdown pipeline diameter was 40mm. To determine the blowdown flowrate for each boiler, a performance graph from blowdown vessel manufacturer, Spirax Sarco was used as shown in Figure 5 below:

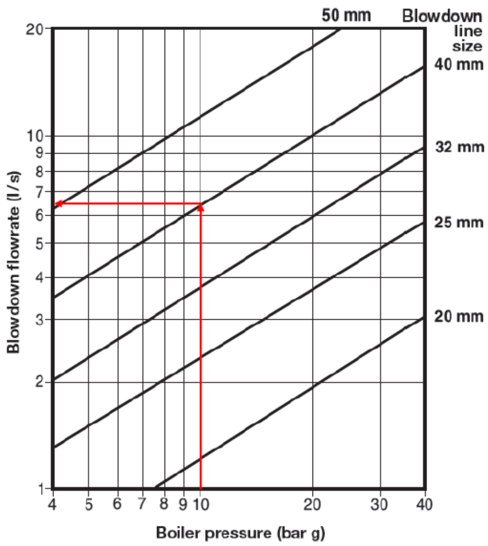

Figure 5: Graph to estimate the blowdown flowrate [29]

From the graph, blowdown flowrate for each boiler was estimated to be 6.5 L/s. For each boiler, the blowdown was done for 45 seconds at 2 to 3 hours. To calculate the number of blowdown for each boiler, it was assumed that blowdown was done for every 2 hours. The number of blowdown in a day can be determined by using Equation 2 below:

Number of blowdown in a day = Operation time of boiler / Gap of blowdown to the next blowdown (Eq 2)

The summary of blowdown system in boiler house of the factory was shown in Table 4 below:

Table 4: Summary of blowdown system in boiler house

Blowdown flowrate of each boiler	6.5 L/s
Number of blowdown in a day	10 times/day.boiler
Volume of blowdown discharged	2.925 m^3/boiler.day
Total volume of blowdown in a day (3 boilers)	8.78 m^3

From the table, the total discharge of bottom blowdown from boilers was 8.78 m^3/day. The discharge entered the blowdown pit, removing the suspended solid formed from chemicals added. As the discharge blown down, there will be huge amount of raw steam containing chemicals released to the surrounding and corroded some parts of equipment such as chimney and feed water tank around the blowdown pit, thus blowdown vessel was suggested to be used and will be discussed in Section D later.

The daily dosage and volume of all the four chemicals in the factory as reported by a boiler water treatment service company named Drew Ameroid (M) Sdn Bhd are shown in Table 5 below:

Table 5: Volume of chemicals used in a day for one boiler

Products	Daily Dosage (kg/tank)	Density (g/cm^3)	Volume (L/day)
Advantage Plus 1400	1.5	9.38	0.16
Amercor 8760	0.3	0.9478	0.32
Ametrol 1123	1.0	1.59	0.63
Biosperse 3001	1.5	1.155	1.30
TOTAL			2.41

Based on Table 5 above, the amount of chemicals added in each boiler was 2.41 L/day, which equivalent to 0.00241 m^3/day. So, the total volume of chemicals added to all boilers were 3 x 0.00241 m^3/day = 0.00723 m^3/day.

As all the unknowns had been determine, the volume of feed water per day can be calculated by using Equation 1. Figure 6 below shows the illustration on material balance of water for three boilers in Ain Medicare Sdn Bhd. From Equation 1, the feed water required by the boiler house in that factory was 153.57 m^3/day. The feed water will be used for producing raw steam that entered the steam header before being supply to production lines. At the same time, some water needed to be blown down to the blowdown pit to remove suspended solid that was formed from chemicals.

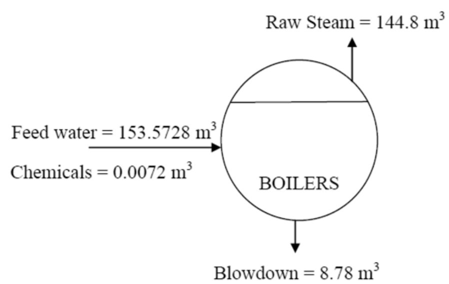

Figure 6: Water balance on boilers in a day.

C. Material Balance On Raw Steam At Boilers

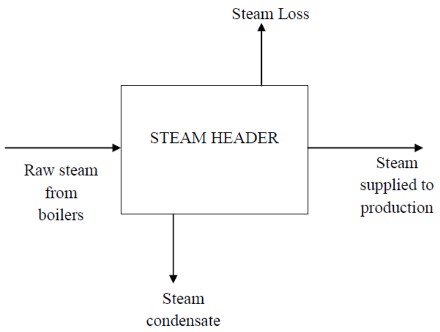

Figure 7: Process flow of raw steam at steam header.

From Figure 7, the raw steam balance at steam header can be represented by Equation 3 below:

Raw steam from boilers = Steam supplied to production + Steam losses + Steam condensate (Eq 3)

From the above equation, only the data for steam losses was not available. The raw steam from boilers can be determine from Mech Mar's catalog as discussed above, while the steam supplied to production and steam condensate was got from previous study conducted by Hashim M.N.N [35]. Steam condensate formed when the raw steam flew through the pipelines and some of the steam will condensate throughout the flow.

For the steam lost, there was a few factors that probably contributed to it. One of the factor was the usage of steam trap, which to discharge the condensate from excessive steam. Some of steam will be lost during processes at the autoclaves and distillers. At autolaves, during the heating process of water for sterilization, some raw steam will vaporized to the atmosphere as there was a safety valve at the heating container. Sometimes, the steam could not be recorded as unknown amount of steam was used especially during sterilization process where steam was used to maintain the temperature of water. While at distillers, the raw steam was used to heat up deionised water to produce pure steam that will then condensed to form water for injection (WFI). During the heating process, the condensate and some of raw steam will be flashed out to the drain.

The raw steam that was supplied to production lines were distributed distillers, autoclaves and heat exchanger. Below are the explanations of each equipment;

i) Distillers

At distillers, the raw steam used as a heating agent to heat up the cooling water, thus it will boiled and form pure steam. Pure steam will be condensed at the condenser and will form water for injection (WFI) that was used to make the products because pure steam was free from all the chemicals and contaminants. At Ain Medicare Sdn Bhd, the average operating time for the distillers were 8 hours/day. Table 6 below shows the steam needed and the calculated steam in a day.

Table 6: Calculation of raw steam needed in a day

Type of distiller	Raw steam needed (kg/hr)	Raw steam needed in a day (kg)	Raw steam needed in a day (m^3)
1000 MS	490	3920	3.92
1500 MS	735	5880	5.88
2000 MS	460	3680	3.68
TOTAL		**13,480**	**13.48**

Therefore, 13.48 m^3 of raw steam needed for the operation of distillers in the factory each day.

ii) Autoclaves

In autoclaves, raw steam used to heat up the cooling water to form hot water, so that it will be use to sterilize the products before being packed into cartons. The average number of run for all autoclaves was 5 runs/day and the operating time was 40 minutes/run. Therefore, the operating in a day was 3.33 hours. Table 7 below shows the raw steam needed per run and the raw steam needed in a day for different type of autoclaves in the factory.

Table 7: Calculation of raw steam needed in a day.

Type of Autoclaves	Raw steam needed (kg/hr)	Total mass of raw steam (kg)	Total volume of raw steam (m^3)
GA1	3300	10,989	10.99
GA2	3180	10,589	10.59
GA3	2760	9,191	9.19
GA4	2760	9,191	9.19
GA5	3300	10,989	10.99
TOTAL		**50,949**	**50.95**

Thus, 50.95 m^3/day of raw steam needed for the operation of all autoclaves in the factory.

iii) Heat Exchanger

In heat exchanger for high purified water (HPW) production line, raw steam was used as a heating agent for haemodialysis fluid. There was one unit of heat exchanger in the production line with the operating time of 16 hours/day. Table 8 below shows the amount of raw steam needed for the operation of heat exchanger.

Table 8: Calculation of raw steam needed in a day.

Type of heat exchanger	Raw steam needed (kg/hr)	Mass of raw steam (kg)	Volume of raw steam (m^3)
High Purified Water	200	3,200	3.2
TOTAL		**3,200**	**3.2**

So, 3.2 m^3/day of raw steam needed for the operation of heat exchanger for high purified water (HPW) production line in the factory.

Table 9: Summary table of raw steam supplied to production lines

Production's equipment	Steam supplied (m^3/day)
Distillers	13.48
Autoclaves	50.95
Heat Exchanger (HPW)	3.20
TOTAL	**67.63**

Table 9 above shows the summary table of the amount of raw steam that was supplied to production lines. In a day, 67.63 m^3 raw steam from boilers will be distributed to distillers, autoclaves and heat exchanger (HPW).

According to Hashim M.N.N [35], the raw steam was condensed at 0.362 kg/hr in every 1 meter of 50 mm pipes. All the pipelines used were assumed to be 50 mm pipes, therefore, for the total pipelines in the pharmaceutical company which was 380 m, the steam condensate was 3301.44 kg/day which equivalent to 3.3 m^3/day. To reduce the energy used for heating the feed water in the boilers, the condensate, which was about 90°C in temperature, will enter the feed water tank. By mixing the condensate with feed water, the heating time in the boiler will also be reduced.

Next, steam lost can be calculated by using Equation 3. Table 10 shows the summary for steam lost:

Table 10: Summary table of steam losses

Volume of steam losses in a day	73.87 m^3
Percentage losses	51.02 %

From the table above, the percentage of raw steam lost in a day was 51.02% which was quite large. To reduce the percentage of raw steam lost, the suggestion was that the operating time for each boiler must be reduce as each operated at 19 hours/day. However, the percentage losses cannot be reduce to 0% due to safety factors and sometimes, the feed water in the boilers must be kept warm so that the usage of fuel can be reduce. Therefore, for the new operating time, the new steam lost was assumed to be 34% including transmission loss and trap loss [42]. Below is the summary table for new amount of raw steam:

Table 11: Summary table of new amount of raw steam

Percentage of steam losses assumed	34%
New amount of steam losses	49.2 m^3/day
New amount of raw steam from boilers	120.16 m^3/day
New steam needed to be produced by a boiler	40.05 m^3/day.boiler
Suggested operating time	11.5 hours/day

For each boiler, the suggested operating time was 11.5 hours/day. Therefore, the current operating time that was 19 hours/day had to be reduced to 11.5 hours/day. Since there were three working shifts in the factory, each boiler had to operate 3.8 hours/shift. To reduce the usage of fuel, the boilers had to alternately operate. For example, one boiler operated for one hour and rest for one hour. During the resting time, the other boiler will operates for another one hour. This will proceed for 24 hours. By resting only for one hour, the hot water in the boiler will remain hot and the time taken for the feed water to boil will be reduce.

D. Blowdown Vessel And Cooling Water Required

As discussed in section B)ii) *Volume of Blowdown Discharge* above, the blowdown flowrate for each boiler in the pharmaceutical factory was 6.5 L/s which equal to 0.293 m^3 for 45 seconds of blowdown.

Due to the air quality issues that occur in the existing boiler house that corroded the nearby equipments, installation of a new equipment to avoid corrosion would be a good option. One of the equipment that can be use was blowdown vessel. Blowdown vessel can cool down the hot blowdown water to a safe temperature and can withstand the pressure up to 20.6 bar. To cool down hot water to the target temperature, some amount of cooling water was required. In this section, the volume of cooling water required will be calculated.

When there was no blowdown, the vessel uses natural convection to cool down the blowdown water to ambient temperature and this process did not require any cooling water [30]. Before the calculation of cooling water required was done, the size of blowdown vessel needed to be determine as stated in Methodology. Equation 4 below is the calculation of standing water inside the vessel according to Spirax Sarco's catalog, which the standing water inside the blowdown vessel should be at least twice of the maximum volume of blowdown [29].

Standing water inside blowdown vessel = 3 boilers x Volume of blowdown x 2 (Eq 4) [29]

From the Equation 4, the standing water inside the vessel was 1755 L. So, based on Table 12, the selected model of vessel was BDV60/12 with standing water of 1825 L which was the nearest to the standing water calculated. The diameter and height of the vessels were 1.8 m and 2.5 m respectively.

Table 21: Sizes, pipe connection, dimension, weight and capacities of blowdown vessel in mm, kg, L [29]

Blowdown vessel type			BDV60/6	BDV60/8	BDV60/10	BDV60/12
Sizes, pipe connections, and dimensions	A	Flanged PN16''	150	200	200	250
	B	Flanged PN16''	100	150	150	150
	C Ova l	Height	100	100	100	320
		Width	150	150	150	420
	D		915	1205	1500	1800
	E		400	400	400	400
	F		630	705	850	840
	G		440	525	590	660
	H		2095	2240	2370	2515
	J		1215	1290	1355	1430
	K		560	705	850	1000
	X		1568	1612	1676	1427
	Y		864	962	1026	-
Number of legs			3	3	3	4
Weights		Empty	392	480	892	1275
		Full	1267	2090	3567	4925
Capacities standing water			437	805	1337	1825

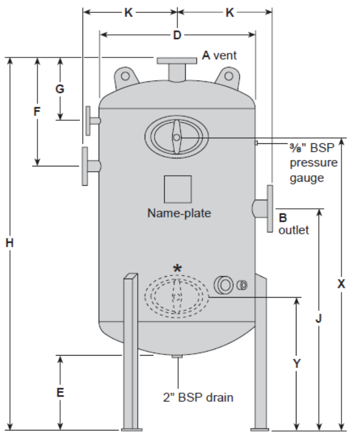

Figure 8: Schematic diagram for blowdown vessel [29]

Figure 9 below shows the schematic diagram for boiler system using blowdown vessel that was suggested to be use for boiler house in the pharmaceutical factory to reduce the air pollution problems.

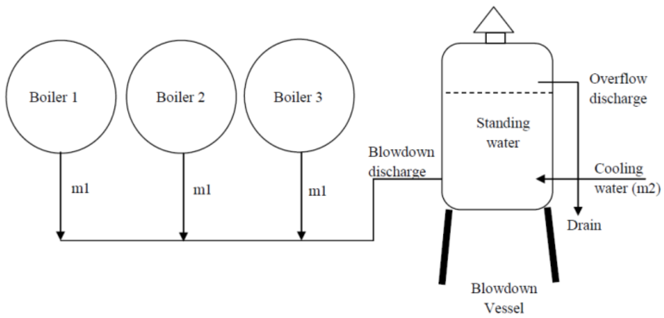

Figure 9: Schematic diagram for boiler system with blowdown vessel

For blowdown vessel, the important thing needed to be know was the amount of cooling water required to mix with the hot blowdown discharge. Due to some limitations, a few assumptions needed to be used to calculate the cooling water required, which were;

a) Some of hot water from blowdown that enter the vessel will be convert to flash steam due to pressure drop. The remaining temperature of blowdown discharge will be 100°C [41].
b) The temperature controller in vessel was set to be 60°C.
c) The temperature of cooling water used was 27°C.
d) Let all the boilers operate at the same time and the blowdown was done in every 2 hours for all the three boilers. The gap of blowdown between each boiler was 30 seconds.
e) Blowdown was done in 45 seconds for each boiler.
f) Number of blowdown in a day for each boiler was 10 times/day as discussed in section B)ii)*Volume of Blowdown Discharge*. So the total number of blowdown for three boilers were 30 times/day.
g) The time for cooling down the discharge by natural convection was 6 to 12 hours [31]. Therefore, the amount of cooling water for the moderate and worst cases will be calculated.

To calculate the amount of cooling water required to cool down the hot water to the target temperature during blowdown, Equation 5 below is used:

$$m_1 Cp_1 \Delta T_1 = m_2 Cp_2 \Delta T_2 \qquad \text{(Eq 5)}$$

where:- m_1 = flowrate of blowdown discharge
Cp_1 = heat capacity of saturated mixture at 10 bar
ΔT_1 = difference in temperature between hot blowdown discharge and standing water
m_2 = flowrate of cooling water
Cp_1 = heat capacity of water at 1 atm
ΔT_1 = difference in temperature between cooling water and standing water

As the time for cooling down the discharge by natural convection were 6 to 12 hours, both moderate and worst cases needed to be set so that the range of cooling water volume can be determine. For the worst cases, the time taken for natural convection takes place was 12 hours while for moderate case, the time taken was 6 hours.

a) Worst Case

Let the natural convection, which the time taken for 60°C water inside the vessel dropped to 27°C to be 12 hours. Therefore, in 2 hours which was the gap between all boilers' blowdown, the amount of temperature drops was 5.5 °C, which meant that the temperature of 60 °C water in vessel will drop to 54.5 °C after 2 hours. As calculated, 11.81 m^3 of cooling water required to mix with hot blowdown discharge in the vessel in order to achieve the target temperature.

b) Moderate Case

For moderate case, let the natural convection, which the time taken for 60°C water inside the vessel dropped to 27°C to be 6 hours. Therefore, in 2 hours, the amount of temperature drops was 11 °C, which meant that the temperature of 60 °C water in vessel will dropped to 49 °C after 2 hours. After calculation, it was found that 10.97 m^3 of cooling water required to be mix with hot water in the vessel in order for the inside temperature to achieve 60 °C.

Below is the graph on the number of blowdown versus cumulative volume of cooling water for both worst and moderate cases.

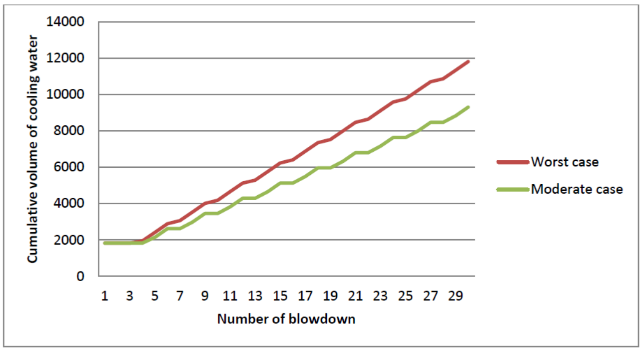

Figure 10: Graph of cumulative volume versus number of blowdown

The patterns of both worst and moderate graphs were almost the same. From the graph, the worst case required more water than moderate case as the time taken to cool down the hot water to the ambient temperature was longer than moderate case. When blowdown vessel was used, 10.97 m^3 of cooling water was required for moderate case and 11.81 m^3 of cooling water was required for the worst case. In Kelantan, the water tariff for industrial usage was RM 1.80 /m^3 [42]. Table 13 below shows the cost of cooling water for both moderate and worst cases.

Table 13: Cost of cooling water required by blowdown vessel in a day

Type	Volume of water in a day (m^3/day)	Cost (RM/day)
Moderate case	10.97	19.75
Worst case	11.81	21.26

Thus, in a day, RM 19.75 to RM 21.26 will be invested for the cooling water when the blowdown vessel was installed. The costs were quite cheap as compare with the cost to repair the corrode equipments that caused by the vaporization of steam when blowdown pit was used. Besides that, the hot blowdown can be discharge in more appropriate manner with lower temperature, which also can reduce the risk of air pollution that can affect human's health.

V. CONCLUSION

In conclusion, in order to reduce the raw steam losses that is produced from boilers, the operation time for each boiler has to be reduce 11.5 hours/day. By reducing the operating time, amount of feed water, chemicals and fuels can be reduced. For the corrosion problem of the equipments nearby blowdown pit, which is caused by vaporization of raw steam, blowdown vessel is suggested to be installed to reduce the air pollution problem. Besides the water can be discharge in more appropriate and safe manner, both volume and cost of total cooling water used are quite low which are 10.97 m^3/day (RM 19.75) for moderate case and 11.81 m^3/day (RM 21.26) for worst case.

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