CERTIFICATION OF APPROVAL

Study of the Use of Orifice as an Alternative for Steam Trap

by

Shakawi Efendy Jamaludin

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Approved by,

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Ir Dr Shaharin Anwar Sulaiman

UNIVERSITI TEKNOLOGI PETRONAS

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

SHAKAWI EFENDY JAMALUDIN

ABSTRACT

Steam traps are vital part of any steam system. Their basic function is to prevent the passage of steam while allowing condensate to flow. A conventional steam trap is simply a self-actuating valve that opens in the presence of condensate and closes in the presence of steam. These traps all have moving parts which, in time will fail. Another non-conventional type of steam trap is known as orifice plate steam trap. The design consist a plate with small hole at the middle to allow condensate to pass through it. It is claim that the trap uses the condensate within its orifice to hold back steam, rather than any valve arrangement. Orifice plate steam traps have no moving parts that can malfunction. Thus, it might be worth to consider the trap for use in steam systems if its size is properly calculated. Under certain circumstances, orifice steam traps could function better than the conventional traps. However the performance of orifice plate steam traps need to be understood. The purpose of this research is to compare the effectiveness of the orifice plate steam trap over variable loads. This was achieved by conducting a few experiments and measuring the rate of steam loss under different condensate loads. Based on the results obtained, a fixed diameter hole was able to pass only a calculated amount of condensate under one set condition. Thus the fixed orifice plate steam trap would not be not suitable for a steam system with variable condensate load. However, if the set of condition is achieved, steam trap orifice would serve better than the conventional orifice steam trap in preserving the steam.

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ABBREVIATIONS AND NOMENCLATURES

DFA	Drain Flange Assembly
DUA	Drain Union Assembly
PSI	Pound square inch
kJ/kg	Kilojoules per kilogram
kg/hr	Kilogram per hour
l/hr	Litre per hour
kJ/kg ^{o}C	Kilojoules per Kilogram-Degree Celcius
kg	kilogram
mm	millimetre

CHAPTER 1

INTRODUCTION

1.0 Background of Study

Steam traps are vital part of any steam system. The steam trap function is to discharge condensate form a steam system, prevent the escape of steam and release air and non-condensable gases from the system. Non-conventional type of steam trap is known as orifice plate steam trap. The design consist a plate with a small hole at the middle to allow condensate to pass through it. It is claimed that the trap uses the condensate within its orifice to hold back steam, rather than any valve arrangement Orifice plate steam traps have no moving parts that can malfunction and thus require less maintenance. For economical reason, it might be worth to consider the trap for use in steam systems if its size is properly calculated.

1.1 Problem Statement

Before additional objective guidance can be provided on when orifice plate steam traps should be considered, additional information and engineering data about the in-service performance of orifice plate steam traps are needed, especially documented case studies of actual orifice plate steam trap installations**.** Although their design is simple, there is always flow of either condensate or live steam through the orifice because there is no way to automatically change the size of the opening or limit the mass flow rate through the orifice When orifice plate steam trap are properly sized for the flow condition, they can function properly but they are not suitable for all operating condition. Steam will escape when no condensate is present and condensate backup can occur during high demand. Orifice plate steam trap are only best suited for situations where the pressure difference across the plate and the condensate load remain constant

1.2 Objectives and Scope of Study

The purpose of this study is to perform efficiency tests over variable loads on a few plate orifice steam trap with different hole size. The data gathered to understand the performance of the orifice plate steam trap, it advantages and disadvantages.

CHAPTER 2

LITERATURE REVIEW

According to the Standard for Production Testing of Steam Traps, Fluid Controls Institute (1989), a steam trap is a self-contained valve that automatically drains the condensate from a steam-containing enclosure while remaining tight to live steam or, if necessary, allowing steam to flow at a controlled or adjusted rate. For a steam system to operate efficiently, each trap must remove condensate as it forms without releasing valuable steam. Steam trap can be divided into conventional steam trap and non conventional steam trap. There are several types of conventional steam traps, each using different actuating mechanisms for detecting the presence of condensate, non-condensable, and steam, as well as several types of discharge valves and valve operating mechanisms. Meanwhile, non-conventional steam trap is known as fixed orifice plate steam trap. An orifice plate steam trap is a relatively simple condensate removal device. Its design includes a thin metal plate with a small diameter hole through the centre. The plate keeps live steam from flowing, and the hole or orifice allows either condensate or a small amount of live steam to escape.

2.0 Steam Trap Application

Steam traps are vital part of any steam system. In the book of Industrial Steam Trapping Handbook, 3rd Ed. Pennsylvania, 1984, steam trap basic function is to prevent the passage of steam while allowing condensate to flow. Its application includes steam pipelines, heat transfer equipment and start-up steam system.

2.1.1 Steam Pipelines

In spite of the fact that steam pipelines are usually well insulated to prevent the loss of heat, some heat will be radiated from the piping. Due to the radiation, the heat carried by the steam is transferred to the wall of the pipeline, causing some of the steam to condense forming condensate (hot water) at the bottom of the pipeline. If this condensate is not removed immediately, it might block up the passage of steam, and thus causing water hammer. It will also extract more steam from the steam and form more condensate.

2.1.2 Heat Transfer Equipment

In heat transferred equipment such as heat exchanger, heat is transferred through the equipment wall to the fluid or product being heated. The condensate form will accumulated at the bottom of the space of the equipment. Like steam pipeline, the condensate need to be remove as soon as it is formed. Otherwise, the process of heat transfer will slow down and finally cease altogether.

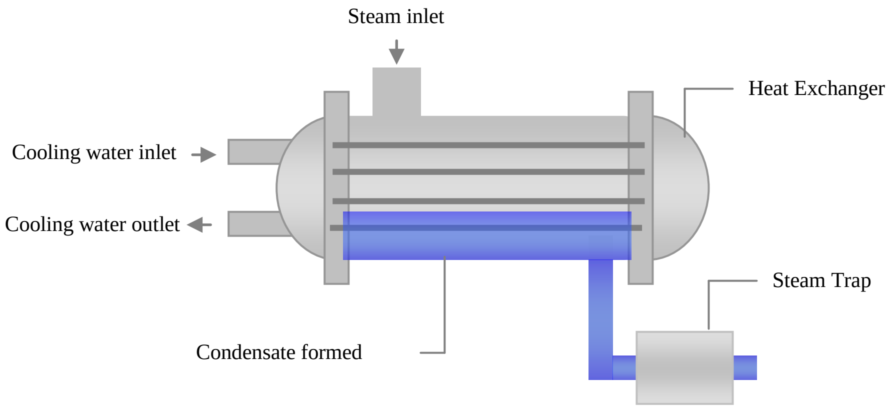

Figure 2.1: Steam trap application for heat exchanger

2.1.3 Start-up of a Steam System

Steam trap especially conventional steam trap required to carry out another function that is not at first apparent. Normally, once a steam system is shutdown, air enters the pipeline and occupies the space left by the condensing steam. Upon start-up, steam that just enter the system will pushed the in the pipeline system into heat transfer equipment. The air might cause decrease of performance of the heat exchanger. This is because these non-condensable gases would act as a barrier to effective heat transfer. Therefore, the steam trap must also be capable of discharging air and non-condensable gases from the system.

2.2 Conventional Steam Trap Operation

Most conventional steam traps used in the chemical process industries fall into one of three basic categories; mechanical traps, thermostatic traps and thermodynamic traps.

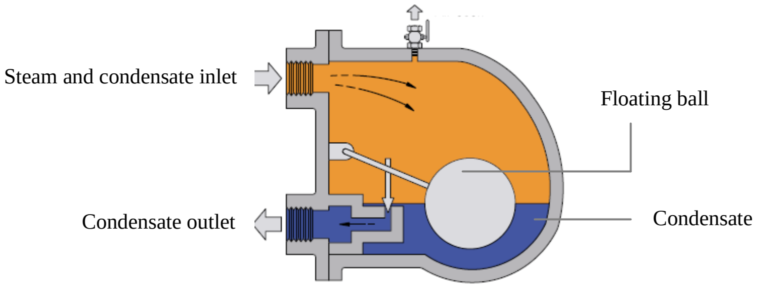

Figure 2.2: Mechanical traps; ball valve steam trap

2.2.1 Mechanical Trap

The trap uses the density difference between steam and condensate to detect the presence of condensate. This category includes float and thermostatic traps and invertedd bucket traps. The condensate removal mechanism of this trap consists of a chamber, a float, and a valve. Condensate flows into the chamber, where it raises a float. The float is attached directly to the discharge valve such that the higher the level of condensate, the more the valve opens. Thus, flow of condensate from this type of trap is continuous, modulating to match the production of condensate in a heat exchanger.

2.2.2 Thermostatic Traps

The trap operates on the principle that saturated process steam is hotter than either its condensate or steam mixed with non-condensable gas. When separated from steam, condensate cools below the steam temperature. A thermostatic trap opens its valve to discharge condensate when it detects this lower temperature. This category of traps includes balanced pressure and bimetal traps as well as liquid and wax expansion thermostatic traps.

2.2.3 Thermodynamic Traps

The traps use the velocity and pressure of flash steam to operate the condensate discharge valve. The trap can be considered normally closed because it consists of a flat, coin-sized disk lying on a flat seat and covering both the inlet and discharge orifices. Cool condensate under process pressure readily flows through the orifice, lifts the disk, and flows over the seat to the discharge orifices. When the condensate is near steam temperature, it flashes as it flows under the disk. This high-velocity flash steam creates a low-pressure area on the bottom of the disk, much like high-velocity air passing over the wing of an airplane. This low pressure between the disk and the seat, combined with a pressure increase above the disk during flow, forces the disk down onto the seat and seals the orifices.

2.3 Non Conventional Fixed Orifice Plate Steam Trap

Removal of condensate from any piece of equipment in a steam system can be accomplished by providing an adequately sized hole or opening at the bottom of each condensate collection point. This opening or orifice allows the condensate to drain freely from the system. A simple orifice plate steam trap consists of a thin metal plate with a small-diameter holed drilled through the plate (American Society of Mechanical Engineers, New York, 1997). When installed at the appropriate location between two adjoining flanges in a steam system as shown in figure 2.3, condensate that accumulates is continuously removed as the steam pressure forces the condensate to flow through the hole.

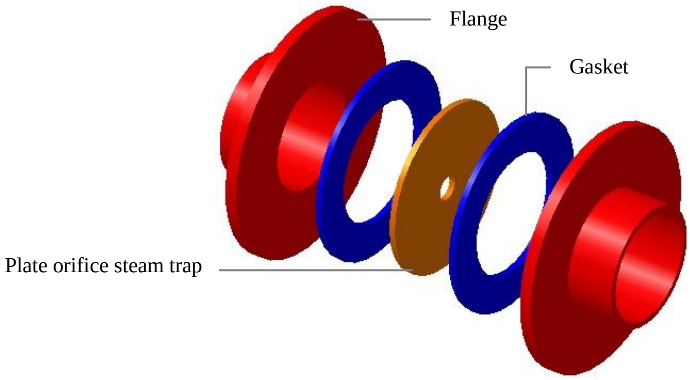

Figure 2.3: Typical installation of fixed orifice steam trap according to Drain Flange Assembly (DFA)

Orifice plate steam trap designs include the DFA and the Drain Union Assembly (DUA), which are described in Ref 6. These assemblies are typically installed in a piping system with threaded rather than flanged connections.

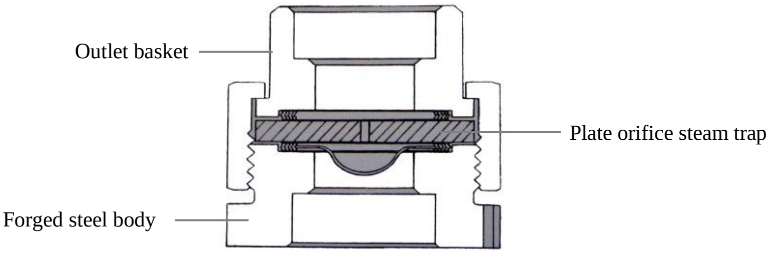

Figure 2.4: Installation of fixed orifice steam trap according to DUA

Orifice plate steam traps have no moving parts that can malfunction. Although their design is simple, there is always flow of either condensate or live steam through the orifice because there is no way to automatically change the size of the opening or limit the mass flow rate through the orifice.

2.4 User Experience

According to McCauley (1995) the U.S Navy investigated opportunities in new steam trapping techniques in 1964, while conducting studies of steam trap operation and maintenance cost. Among the concepts investigates was that of using a fixed orifice to meter only the condensate produce in particular application. The researcher’s reason; that if a fixed sized orifice was used to pass only the quantity of condensate produced, then the steam emitted from the orifice, under conditions when no condensate was present would be minimal. This steam loss although minute is greater than that encountered if a properly functioning conventional steam trap were in its place. Today after more than thirty years of use the orifice trap is still used exclusively in the fleet. Results have been more than satisfactory.

According to Oland (1996), “Contacts were made with individuals from the U.S. Air Force, a university, and a private company. Information about the use of orifice plate steam traps by the U.S. Navy was obtained from published sources. To help the Air Force make an informed decision about replacing approximately 5000 steam traps at Hill Air Force Base in Utah, a steam trap testing program was conducted by a steam trap manufacturer. The objective of the testing program was to compare the performance of fixed orifice steam traps with conventional steam traps under the same operating conditions. In the side by- side tests that were performed at the manufacturer facility, various test conditions were evaluated. At least five of the test conditions were selected by Hill Air Force Base personnel to reflect pressures and temperatures typically encountered in different parts of their steam system.

When the testing was completed and the data were analyzed, the Air Force concluded that fixed orifice steam traps only performed satisfactorily under one set of operating conditions. Based on this conclusion, the decision was made to continue using conventional steam traps at Hill Air Force Base rather that replace them with fixed orifice steam traps.” Oland (1996) further added that more than 100 locations within the steam system of University of North Dakota were installed with fixed orifice steam trap However, after some time, all of the traps were removed for variety of reason. There was a confusion of whether the trap was clogged or if the steam was flowing. Waterlogging problem was also experience. However, there was no comprehensive report prepared.

2.5 Sizing Orifice Steam Trap

Sizing an orifice can easily been done by knowing condensate loads, the safety factor to use, pressure differential and maximum allowable pressure. Table 2.1 defines the applicable safety factor for the equipment to which the orifice trap is to be connected. The safety factor will vary from a low of 1.5: 1 to a high of 10:1. The safety factor is based on years of user experience.

Table 2.1: Orifice steam trap application safety factors

NO	APPLICATION	SAFETY FACTOR
1	Main steam supply • Outdoors • Indoors	 1.25 1.5
2	Trace heating	1.10
3	Space heater	1.0
4	Process heater	1.1 to 1.25
5	Water heater	1.1 to 1.25
6	Cylinder dryers	1.5

Maximum differential pressure is the difference between boiler or steam main line or the downstream pressure of a pressure relief valve and return line pressure. The trap must be able to open against this differential pressure. The maximum condensate load needs to be determined through calculation. The formula depend on which the trap application and configuration. The design load for the orifice steam trap is calculated as follow:

$$\text{Design load} = \text{Maximum condensate load} \times \text{Safety factor} \qquad (1)$$

The graphs of Condensate Flow vs. Pressure Drop for a selection of orifices in the range of 1-50 PSIG is shown in Appendix 1. With the design load and the orifice inlet pressure, the orifice diameter can easily be determined.

2.6 Maximum Condensate Load

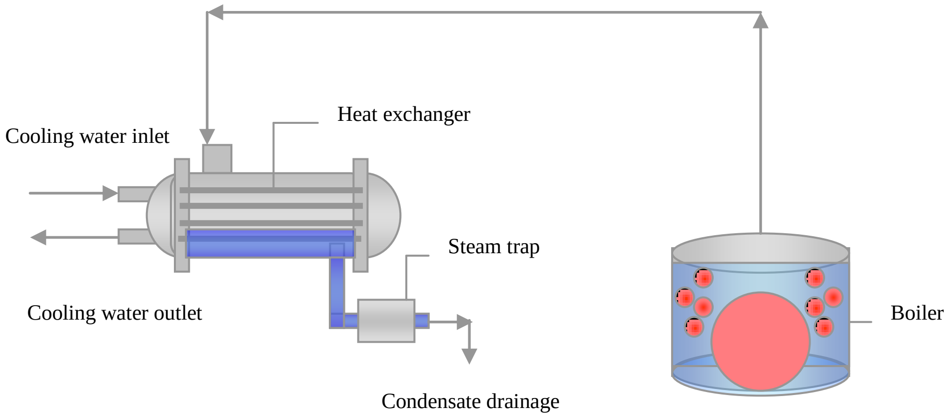

Figure 2.5: Schematic of the small steam system

Figure 2.5 shows a simple steam system. The boiler will produced steam that will travel through pipeline into heat exchanger. In heat exchanger, the steam will start to condense and forming condensate. This condensate will be removed as soon as it formed to maintain the effectiveness of the heat exchanger. Steam trap will ensure that only condensate will be removed without releasing any valuable steam. The condensate load is calculated using the following formula:

$$Q_{load} = \frac{Q_{cw} \times (T_{in} - T_{out}) \times C \times S_g}{H} \qquad (2)$$

Q_{load} : Condensate loads in kg/hr

Q_{cw} : Cooling water flow in l/hr

T_{in} : Inlet temperature of cooling water in ^{o}C

T_{out} : Outlet temperature of cooling water in ^{o}C

C : Specific heat of cooling water in kJ/kg ^{o}C

S_g : Specific gravity of cooling water

H : Latent heat of steam in kJ/kg

2.7 The Release of Flash Steam

High pressure condensate forms at the same temperature as the high pressure steam from which it condenses, as Latent Heat (enthalpy of evaporation) is removed. When this condensate is discharged to a lower pressure, the energy it contains is greater than it can hold while remaining as liquid water. The excess energy re-evaporates some of the water as steam at the lower pressure. Conventionally this steam is referred to as "Flash Steam", although in fact it is perfectly good steam even if at a low pressure.

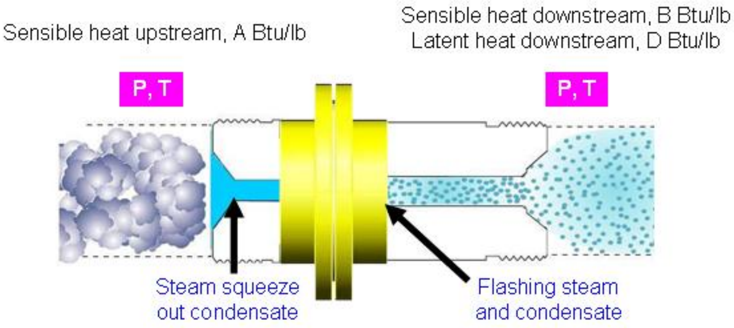

Figure 2.6: Determining the percentage of flashing steam

Below is the formula to calculate the ratio of flashing steam.

Sensible heat upstream = A kJ/kg

Sensible heat downstream = B kJ/kg

Latent heat at downstream = C kJ/kg

Flashing steam ratio $= \dfrac{(A-B)}{C}$

The quantity of flash steam expected downstream of the orifice for given the orifice size and inlet and outlet pressure is shown in Appendix 2.

CHAPTER 3

METHODOLOGY

3.0 Project Flow

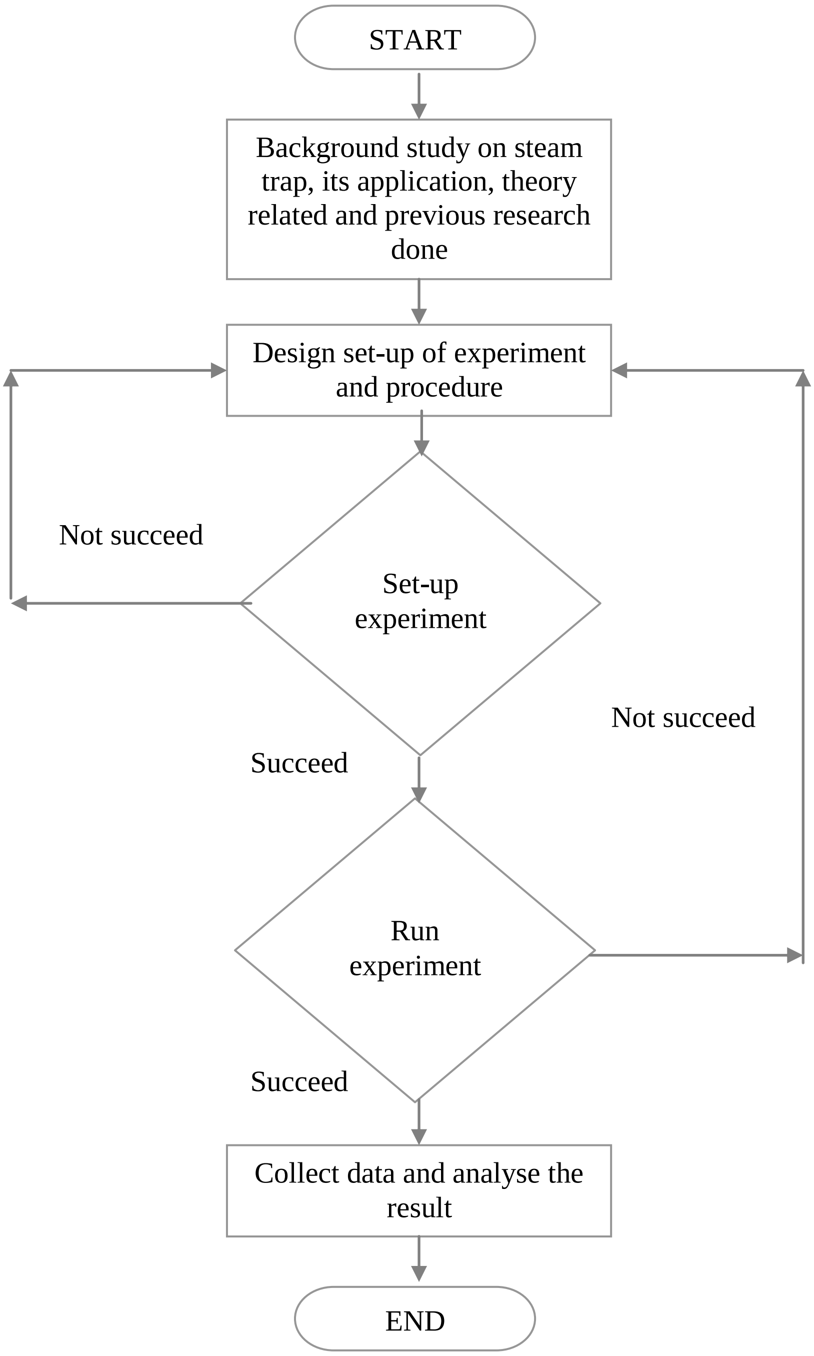

Figure 3.1: Project flow

The flow of the project is shown in Figure 3.1. The purpose of this study is to perform efficiency tests over variable loads on a few plate orifice steam trap with different hole size. The system studied consists of steam and condensate. Experiments were performed in achieving the objectives since there was no software that was able to analyze two phase liquid. The steam trap functions, types, application as well as some other user experience were studied to gain some insight of steam trap performance. The experiment setup as well as the procedure was design and it was required to be relevant to the objectives of the project. A few setups were analyzed and the final setup is depicted in Figure 3.3. Refer to Section 3.1 for the experimental design explanation. An additional device which is the plate orifice steam trap in Figure 3.4 is then being installed to complete the experiment setup. The experiment was done for three times utilizing three different size of orifice plate steam trap and all the required data collected is shown in Tables 4.1 to 4.3. Calculation was made to determine the rate of steam loss over variable load. Based on the result obtained, the performance of the trap was analyzed and the conclusion was made discussing on performance of the trap under variable load.

3.1 Design of Experiment

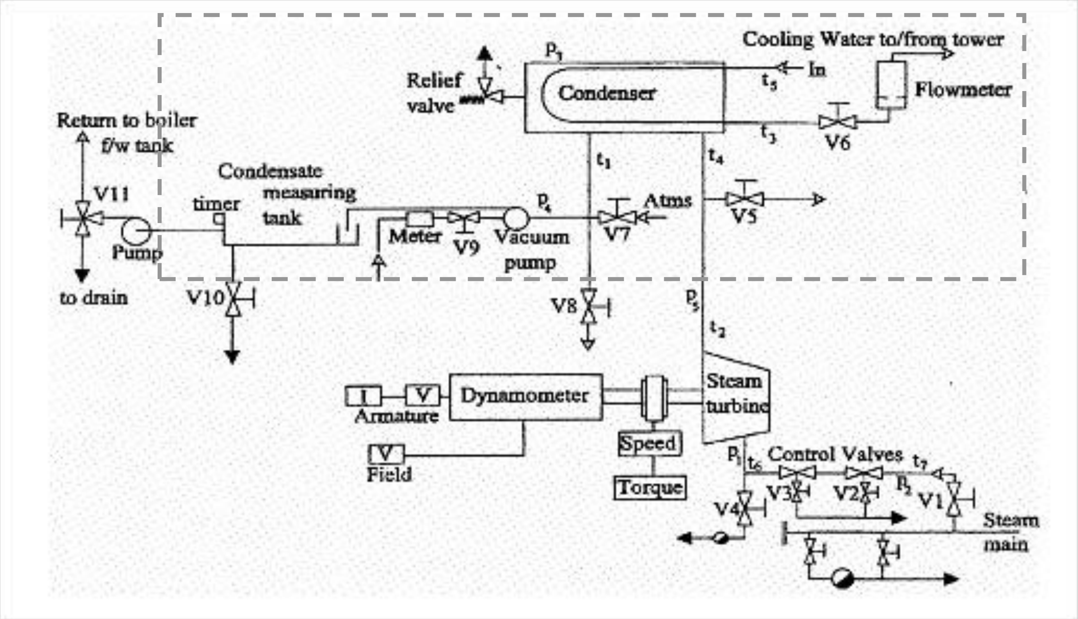

Figure 3.2: Schematic arrangement of steam turbine/condenser set

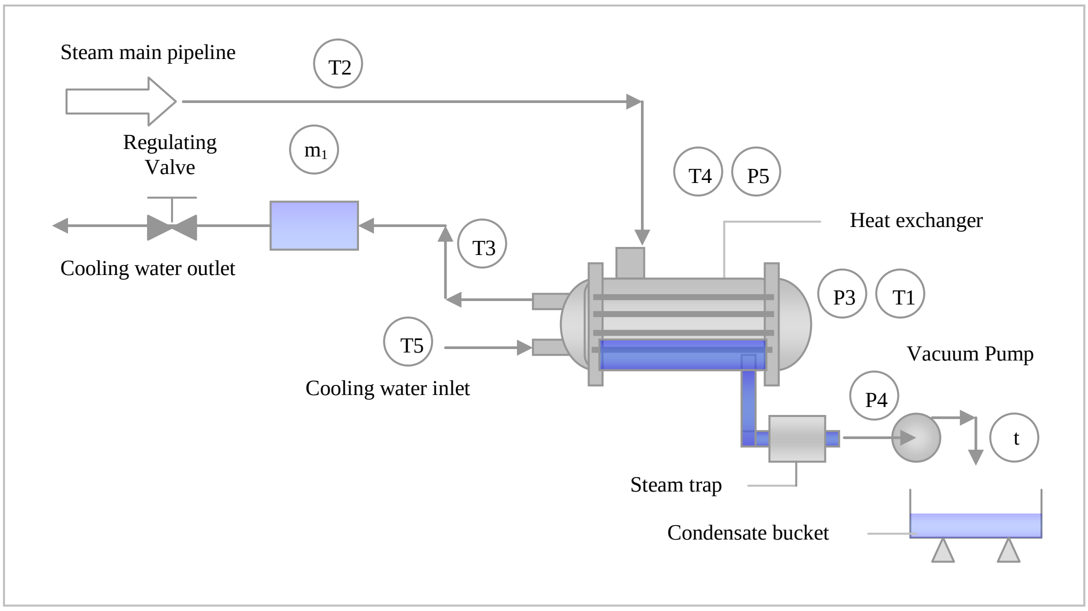

Figure 3.3: Design of experiment

The set up depicted in Figure 3.3 was chosen. The steam travelled through pipeline into heat exchanger. In heat exchanger, the steam condensed and form condensate. This condensate was removed as soon as it formed to maintain the effectiveness of the heat exchanger. Steam trap function is to ensure that only condensate was removed without releasing any valuable steam. All the steam will be collected inside the condensate bucket before discharged. The vacuum pump is required to drive the flow of the steam and condensate form heat exchanger into the condensate bucket.

The purpose of this study is to perform efficiency tests over variable loads on a few plate orifice steam trap with different hole size. The condensate loads, is altered by regulating the flow of cooling water supply on the secondary side of the exchanger. This changes the rate of heat transfer of the exchanger without any change in steam pressure. The forming condensate rate is calculated as it collected inside the condensate bucket that. Meanwhile any uncondensed steam that was able to pass trough the orifice will be discharged to the surrounding. The rate of steam loss over variable load for different orifice sized was determined by completing the calculation in equation (4). The data was used to gives understanding on how the trap performed.

The need to regulate the steam load is to satisfy the claims of the orifice trap manufacturer in that arguably the most testing conditions are exerted on their trap - that of full steam pressure with a full range of condensate flows. Thus, the data will enable us to visualize on how steam trap will function in the real world where the pressure and temperature is not constant and the condensate load vary over time. Table 3.1 summarized the function of each of the equipment involved

Table 3.1: Equipment and their function

NO	EQUIPMENT	DESCRIPTION
1	Heat exchanger	To condense the steam coming from steam main pipeline
2	Steam trap	To trap steam coming from heat exchanger while allow condensate to passed through into the bucket
3	Cooling water supply	To condense the steam inside heat exchanger
4	Condensate bucket	To collect all the condensate as well as flashing steam coming from the heat exchanger that passed through the steam trap. It is equipped with sensor to measure the condensate rate.
5	Vacuum pump	To drive the flow of condensate and flashing steam coming from heat exchanger into condensate bucket
6	Regulating valve	To controlled the flowrate of cooling water

However it is noted that most variable load applications in industry are fitted with control valves and so as the heat loads vary, the steam pressure will be regulated. Thus at low loads there will be less condensate produced and less steam pressure exerted on the trap. So any steam losses through the orifice trap at low loads, when there is less condensate present to hold back steam, will be negligible compared to those where full steam pressure is present while condensate loads are varied.

3.2 Procedure and Calculation

Tests were performed at a constant steam pressure of 8 bar and varying cooling water flows of 10 L/s to 6.5 L/s. The cooling water flow rate was adjusted in order to varying the condensation rate. Three tests with different orifice plate sized were conducted. The plate was made of mild steel and fabricated using electrical discharge machining. The sizes of orifice plate used were 4 mm, 4.5 mm and 5 mm as shown in Figure 3.4.

Figure 3.4: Fixed orifice plate with size of 4.0 mm, 4.5 mm and 5.0 mm

The orifice plate with gasket after installed between condenser and vacuum pump as shown in Figure 3.5. Vacuum pump is function to drive the flow of steam escape from the orifice and condensate formed from heat exchanger.;

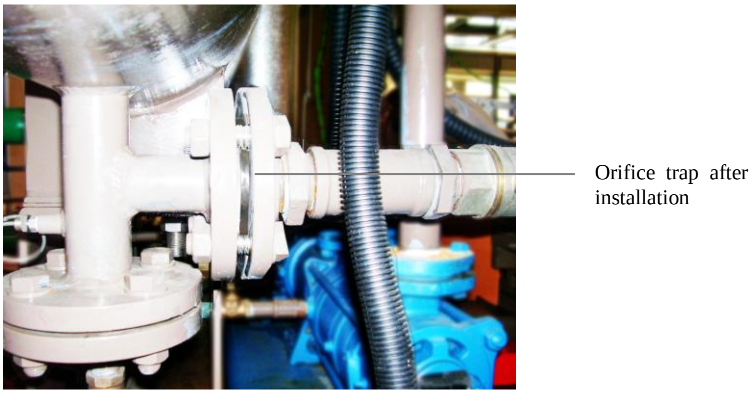

Figure 3.5: Steam trap installation

Gasket was inserted between the flange and the plate to ensure there would be no steam escape. From Figure 3.3, the reading of temperature (T1 until T7) and pressure (P1 until P5) were taken. To measure the condensate load the equation below were used:

$$Q_{load} = \frac{Q_{cw} \times (T_{in} - T_{out}) \times C \times S_g}{H} \qquad (2)$$

Q_{load} : Condensate loads in kg/hr

Q_{cw} : Cooling water flow in l/hr

T_{in} : Inlet temperature of cooling water in ^{o}C, (T5)

T_{out} : Outlet temperature of cooling water in ^{o}C, (T3)

C : Specific heat of cooling water in kJ/kg ^{o}C

S_g : Specific gravity of cooling water

H : Latent heat of steam in kJ/kg

The condensate load was adjusted by modifying the cooling water flowrate, m$_1$. This is done by regulating the flow control valve of the cooling water as shown in Figure 3.6. The maximum cooling water flowrate is 10 L/hr and it was adjusted to decrease in decrement of 0.5 l/hr until 6.5 l/hr.

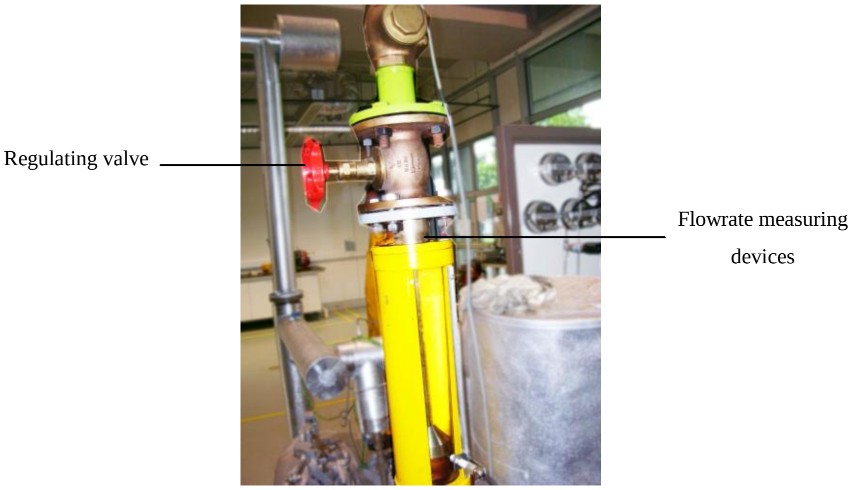

Figure 3.6: Cooling water flowrate measuring devices with regulating valve

The maximum steam flowrate was taken at the beginning of the experiment. This is measured during the cooling water flowrate is maximum, thus all of the steam is condense. All of the steam that condensed will enter the condensate bucket as shown in Figure 3.7. By measuring the time, *t* taken for 15 kg of condensate to be collected, the steam flowrate can be determined. The condensate bucket is also used to measure of the time taken for 15 kg condensate to be collected. This data is used in determining the amount of net rate of steam loss.

Figure 3.7: Condensate bucket measuring tank

After the steam pass through the trap, some amount of steam will flash. The percentage of flashing steam is determined as follow;

Sensible heat upstream = A kJ/kg
Sensible heat downstream = B kJ/kg
Latent heat at downstream = C kJ/kg
Flashing steam percentage = $\frac{(A-B)}{C}\times 100$ (3)

To determine the sensible heat and latent heat of steam/condensate, the reading of P3, P4 and P1 is required. By knowing the amount of condensate that flashes into steam, the amount of net steam loss can be determined trough equation below;

Net Rate of live steam loss, Q_{loss} = Steam flowrate – Condensate collected flowrate - Flasing steam flowrate where,

Steam flowrate coming from boiler $= Q_{steam}$

Rate of accumulated condensate collected $= \frac{15kg}{t}$

Steam flash to vapour $= \frac{(A-B)}{C}$ x Condensate load

Net Rate of live steam loss, Q_{loss} $= Q_{steam} - \frac{15kg}{t} - \left[\frac{(A-B)}{C} \times Q_{load}\right]$ (4)

The data calculated was plotted in graph of Rate of Live Steam Loss versus Condensate Load for three different size of orifice. The data was then analysing to measure the performance of orifice plate steam trap.

CHAPTER 4

RESULT AND DISCUSSION

4.0 Calculations

Below is a sample of calculation which refers to that data set No.1 in Table 4.1

Condensate collected : $\frac{15kg}{191.5\sec}$

: $0.07832981 kg/\sec$

: $281.8 kg/hr$

The latent heat of the steam based on pressure of P3 and Temperature T1. Using equation (2) the condensate load is:

Condensate load, Q_{load} : $\frac{10l/s \times \times 3600 \times (31-26) \times 4.195 kJ/kg.K \times 1}{2626.751 kJ/kg}$

: $287.4 kg/hr$

$287.4 kg/hr$ is the maximum amount of steam flowrate for the experiment. This will be used in determining the amount of net steam loss for the entire calculation of the experiment. After the condensate pass through the orifice, some amount of condensate will flash. Using equation (3) amount of condensate that flash is as follow:

Flashing steam : $\frac{(289.23-251.4)}{2358.3} \times 287.4654$

: $4.6\ kg/hr$

Using equation (4), the net rate of live steam loss is calculated as follow:

Rate of live steam loss : $287.4654 kg/hr - 281.84332 kg/hr - 4.611294 kg/hr$

: $0.86\ kg/hr$

4.1 Result

Table 4.1: Experiment result for flow orifice with size of 4.0 mm

No		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Condensate, T1	C	45	46	46	47	48	48	49	50
Turbine Exhaust, T2	C	72	72	71	69	68	69	70	70
Cooling Water Outlet, T3	C	31	32	31	31	31	31	31	32
Condenser Steam Inlet, T4	C	71	72	70	68	68	69	68	68
Cooling Water Inlet, T5	C	26	27	26	26	26	26	26	27
Nozzle Inlet, T6	C	147	148	149	148	147	147	148	147
Steam Line, T7	C	176	176	177	179	178	177	176	177
Nozzle Inlet, P1	Bar	5	5.2	5.1	4.9	4.9	4.8	4.9	4.7
Steam Line, P2	Bar	8.2	8.5	8.2	8.2	8.3	8.4	8.3	8.4
Condenser, P3	Bar	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7
Condenser Exhaust, P4	Bar	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8
Turbine Exhaust, P5	Bar	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7
Cooling Water Flowrate	L/s	10	9.5	9	8.5	8	7.5	7	6.5
Condensate	kg	15	15	15	15	15	15	15	15
Condensate Time	sec	191.5	193.4	192.7	200	220.4	235.8	250.8	300
Condensate Collected	kg/hr	281.98	279.21	280.22	270	245.	229.00	215.31	180
Latent Heat of Steam	kJ.kg	2626.75	2630.69	2626.82	2626.75	2626.75	2624.88	2626.75	2626.75
Specific Heat of Cooling Water	kJ/kg.K	4.195	4.195	4.195	4.195	4.195	4.195	4.195	4.195
Specific Gravity	-	1	1	1	1	1	1	1	1
Condensate Load	kg/hr	287.47	272.68	258.71	244.35	229.97	215.75	201.23	186.85
Sensible Heat Upstream	kJ/kg	289.23	289.23	289.23	289.23	289.23	289.23	289.23	289.23
Sensible Heat Downstream	kJ/kg	251.4	251.4	251.4	251.4	251.4	251.4	251.4	251.4
Latent Heat Downstream	kJ/kg	2358.3	2358.3	2358.3	2358.3	2358.3	2358.3	2358.3	2358.3
Flashing Steam	kg/hr	4.61	4.37	4.15	3.92	3.69	3.46	3.23	2.99
Rate of Steam Loss	**kg/hr**	**0.87**	**3.88**	**3.09**	**13.55**	**38.77**	**54.99**	**68.93**	**104.47**

Table 4.2: Experiment result for flow orifice with size of 4.5mm

No		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Condensate, T1	C	47	46	48	47	48	47	47	49
Turbine Exhaust, T2	C	69	68	70	72	67	70	69	68
Cooling Water Outlet, T3	C	31	30	31	30	30	30	30	30
Condenser Steam Inlet, T4	C	68	69	71	70	67	68	69	66
Cooling Water Inlet, T5	C	26	25	26	25	25	25	25	25
Nozzle Inlet, T6	C	150	151	150	149	148	149	148	148
Steam Line, T7	C	176	177	178	179	178	178	179	177
Nozzle Inlet, P1	Bar	5.1	5.1	5	4.9	4.8	4.9	5	4.8
Steam Line, P2	Bar	7.9	8.2	8	8.1	8.2	8.3	8.3	8
Condenser, P3	Bar	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7
Condenser Exhaust, P4	Bar	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8
Turbine Exhaust, P5	Bar	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7
Cooling Water Flowrate	L/hr	10	9.5	9	8.5	8	7.5	7	6.5
Condensate	kg	15	15	15	15	15	15	15	15
Condensate Time	sec	190.7	195.8	208	220	235.8	247.6	265.4	290.4
Condensate Collected	kg/hr	283.17	275.79	259.62	245.45	229.01	218.09	203.47	185.95
Latent Heat of Steam	kJ.kg	2622.95	2624.81	2628.75	2626.82	2621.01	2622.95	2624.81	2622.95
Specific Heat of Cooling Water	kJ/kg.K	4.195	4.195	4.195	4.195	4.195	4.195	4.195	4.195
Specific Gravity	-	1	1	1	1	1	1	1	1
Condensate Load	kg/hr	287.88	273.29	258.52	244.34	230.48	215.91	201.37	187.12
Sensible Heat Upstream	kJ/kg	289.23	289.23	289.23	289.23	289.23	289.23	289.23	289.23
Sensible Heat Downstream	kJ/kg	251.4	251.4	251.4	251.4	251.4	251.4	251.4	251.4
Latent Heat Downstream	kJ/kg	2358.3	2358.3	2358.3	2358.3	2358.3	2358.3	2358.3	2358.3
Flashing Steam	kg/hr	4.62	4.38	4.15	3.92	3.70	3.46	3.23	3.00
Rate of Steam Loss	**Kg/hr**	**0.097**	**7.71**	**24.12**	**38.51**	**55.18**	**66.33**	**81.19**	**98.93**

Table 4.3: Experiment result for flow orifice with size of 5.0mm

No	1	2	3	4	5	6	7	8	9
Condensate, T1	C	48	46	47	48	48	45	46	49
Turbine Exhaust, T2	C	70	69	68	71	69	68	70	69
Cooling Water Outlet, T3	C	30	31	32	30	31	30	32	32
Condenser Steam Inlet, T4	C	72	69	68	72	71	70	70	68
Cooling Water Inlet, T5	C	25	26	27	25	26	25	27	27
Nozzle Inlet, T6	C	155	152	150	151	150	150	152	153
Steam Line, T7	C	177	178	179	180	181	180	179	180
Nozzle Inlet, P1	Bar	5.2	5	5.1	5	5.2	5.2	5	5.1
Steam Line, P2	Bar	8.2	8.2	8.3	8.1	8	8.2	8.3	8.1
Condenser, P3	Bar	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7
Condenser Exhaust, P4	Bar	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8
Turbine Exhaust, P5	Bar	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7
Cooling Water Flowrate	L/s	10	9.5	9	8.5	8	7.5	7	6.5
Condensate	Kg	15	15	15	15	15	15	15	15
Condensate Time	sec	193.2	193.5	211.1	215.6	235.8	243.8	260.2	287.7
Condensate Collected	Kg/hr	279.50	279.07	255.80	250.46	229.01	221.49	207.53	187.70
Latent Heat of Steam	kJ.kg	2630.69	2624.81	2622.95	2630.69	2628.75	2626.82	2626.82	2622.95
Specific Heat of Cooling Water	kJ/kg.K	4.20	4.20	4.20	4.20	4.20	4.20	4.20	4.20
Specific Gravity	-	1	1	1	1	1	1	1	1
Condensate Load	kg/hr	287.04	273.29	259.09	243.98	229.80	215.59	201.22	187.12
Sensible Heat Upstream	kJ/kg	289.23	289.23	289.23	289.23	289.23	289.23	289.23	289.23
Sensible Heat Downstream	kJ/kg	251.4	251.4	251.4	251.4	251.4	251.4	251.4	251.4
Latent Heat Downstream	kJ/kg	2358.3	2358.3	2358.3	2358.3	2358.3	2358.3	2358.3	2358.3
Flashing Steam	kg/hr	4.60	4.38	4.16	3.91	3.68	3.46	3.23	3.00
Rate of Steam Loss	**kg/hr**	**2.93**	**3.58**	**27.08**	**32.66**	**54.34**	**62.08**	**76.27**	**96.34**

4.2 Discussion

Figure 4.1 shows a typical example of the test result form a range of test conducted at condensate load of 244 kg/hr.

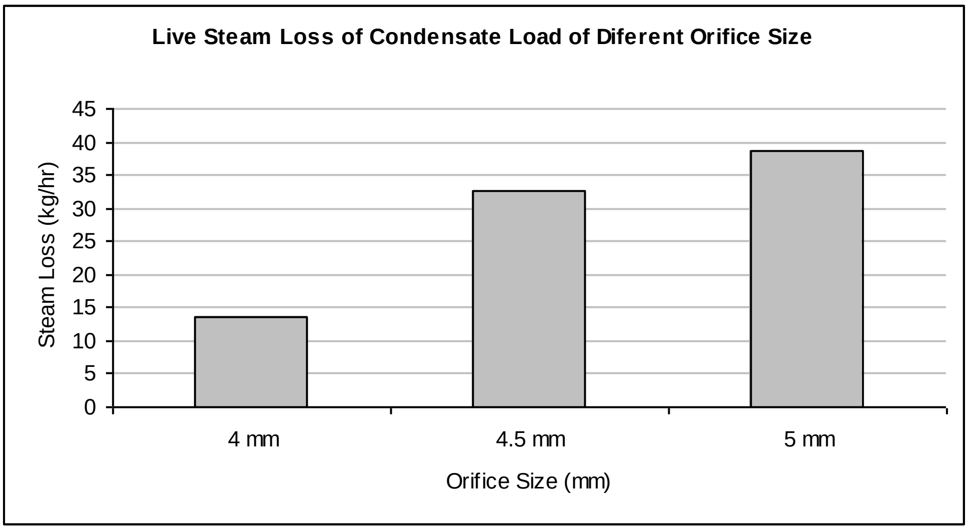

Figure 4.1: Comparison of steam loss for condensate load 244 kg/hr for different orifice size

As shown in the result in Figure 4.1, under the same condensate load, the amount of steam loss through the orifice is different for different size of orifice. For condensate loads of 244k g/hr, the orifice with size of 4.0 mm loss steam about 14 kg/hr while 4.5 mm with loss of 32 kg/hr and 5.0 mm with loss of 39 kg/hr. The trend shows that the bigger the size of orifice, the more the amount steam loss will be. The steam trap is supposed to pass only condensate without releasing any valuable steam. Thus it is important to calculate the exact amount of condensate load or condensate rate. When determining the orifice size, a designer has to select a small enough orifice to keep too much live steam from escaping and a large enough orifice to keep condensate from backing up.

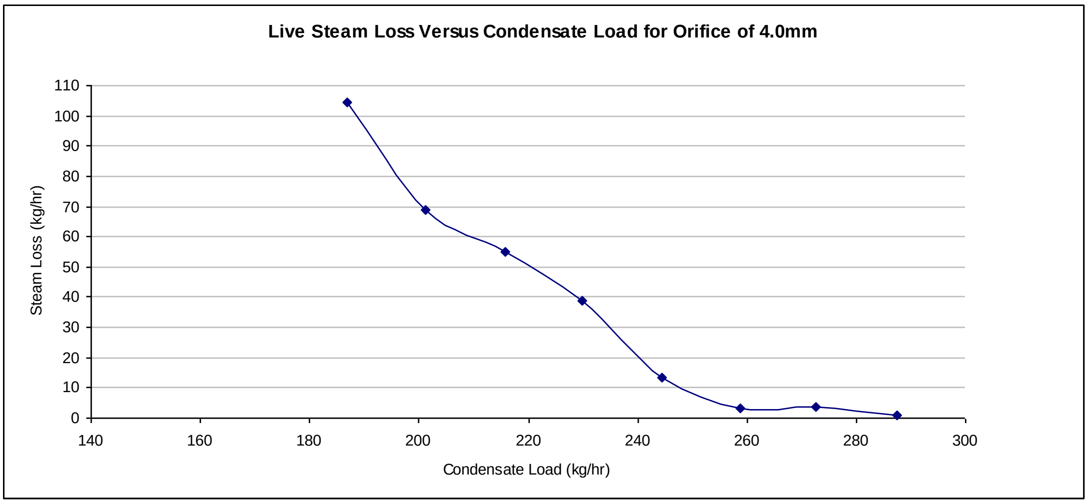

Figure 4.2: Live steam loss for varying condensate load for orifice size of 4.0 mm

Figure 4.2 show the amount of net steam loss for orifice size of 4.0 mm for condensate load varying between 190 kg/hr to 280 kg/hr. The amount of steam loss starts increase drastically below the condensate load of 260 kg/hr.

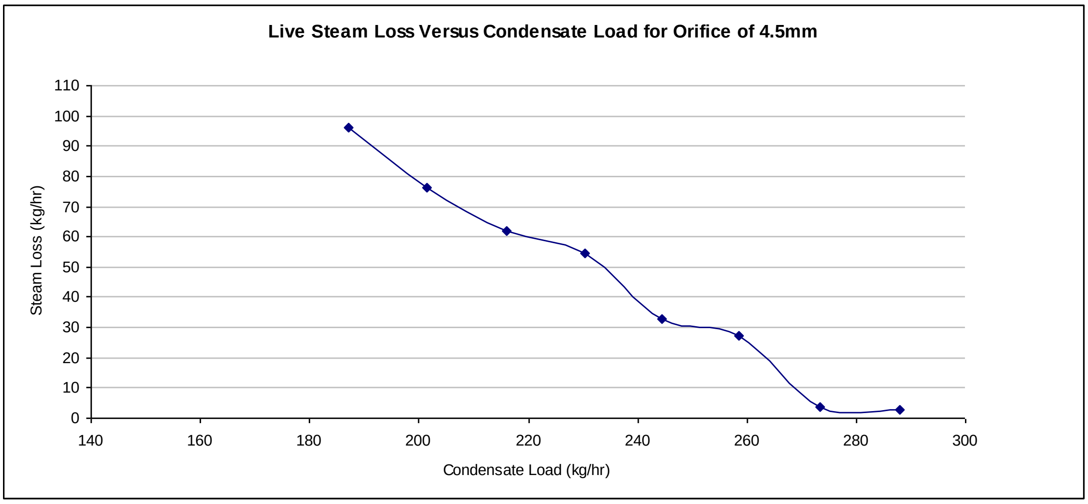

Figure 4.3: Live steam loss for varying condensate load for orifice size of 4.5 mm

Figure 4.3 show the amount of net steam loss for orifice size of 4.5 mm for condensate load varying between 190 kg/hr to 280 kg/hr. The amount of steam loss starts increase drastically below the condensate load of 275 kg/hr.

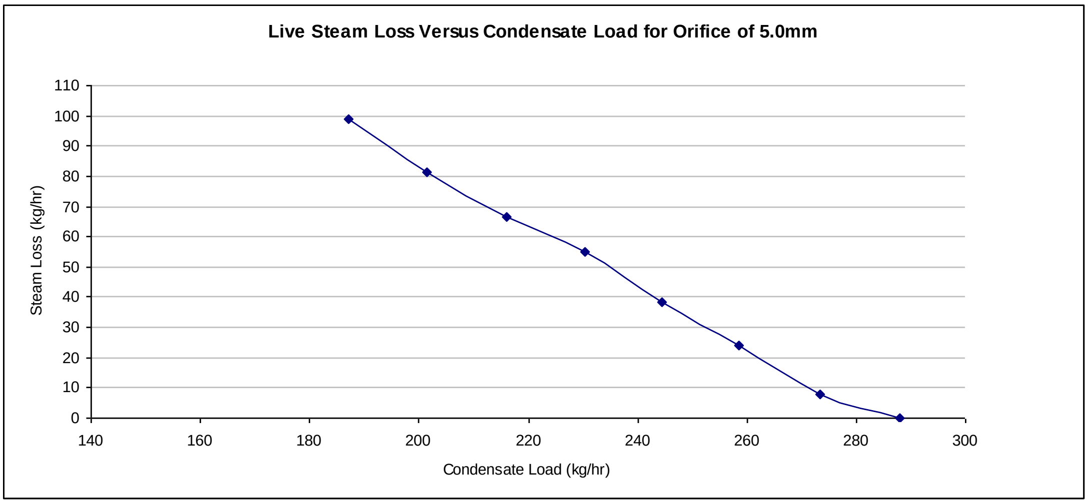

Figure 4.4: Live steam loss for varying condensate load for orifice size of 5.0 mm

Figure 4.4 show the amount of net steam loss for orifice size of 4.5 mm for condensate load varying between 190 kg/hr to 280 kg/hr. The combined results from Figure 4.2 until Figure 4.4 are shown in Figure 4.5.

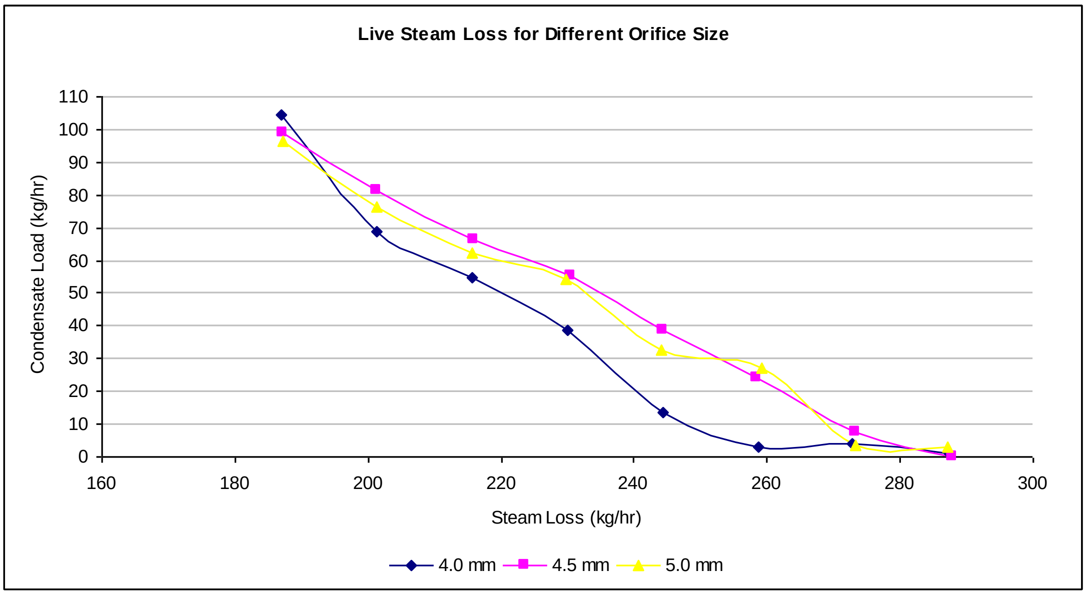

Figure 4.5: Comparison of steam loss for varying condensate load for orifice size of 4.0 mm, 4.5 mm and 5.0 mm

From Figure 4.5, steam will always escape through the orifice although the amount can be considered negligible. As stated in problem statement, there is always flow of either condensate or live steam through the orifice because there is no way to automatically change the size of the opening or limit the mass flow rate through the orifice. Compared to conventional steam trap, the valve will fully close when there is no condensate. Thus it can be considered as one of disadvantages of orifice plate steam trap.

Orifice plate steam trap with size of 4.0 mm start to loss more steam below 260 kg/hr. Orifice plate steam trap with size of 4.5 mm start to loss more steam below 275 kg/hr. Orifice plate steam trap with size of 5.0 mm start to loss more steam below 290 kg/hr. Thus we can say that a different set of operation. For example, the optimum performance of orifice plate steam trap with orifice size of 4.0 mm is for a condensate load of 260 kg/hr. The optimum orifice plate steam trap working situation is shown in Figure 4.5.

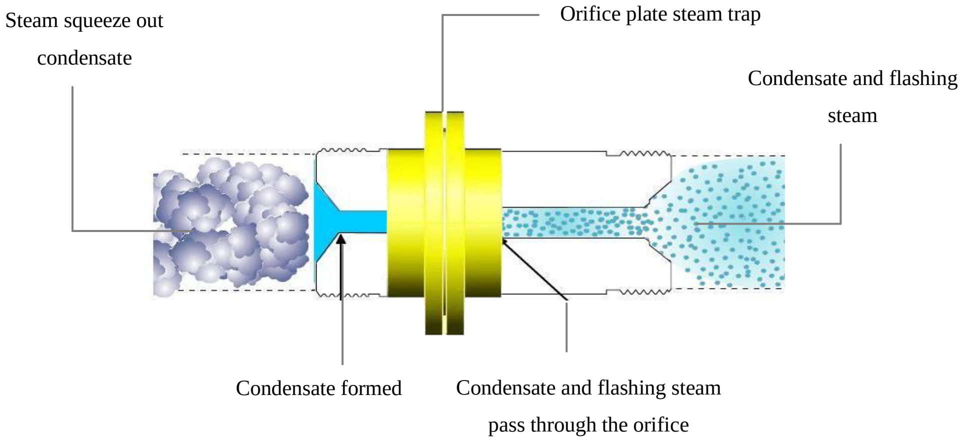

Figure 4.6: Optimum orifice plate steam trap working situation

If the optimum performance of the orifice plate steam trap is achieved, the condensate mass flow rate through the orifice is sufficient to keep condensate from backing up and live steam from escaping. As the steam radiate out its heat and forming condensate, the condensate will pass though the orifice and some of them will flash. The condensate also forms a seal that prevent the steam from heat exchanger from passing through the orifice. At the same time, the steam will squeeze out the condensate to pass through the orifice and allow continuous flowing system. As long as the rate of steam that condense and forming condensate is the same with the rate of condensate passing through the orifice, the orifice plate steam trap is in it optimum working condition. For 4.5 mm orifice, optimum performance is achieved for condensate load of about 275 kg/hr and 5.0 mm with condensate load of 290 kg/hr.

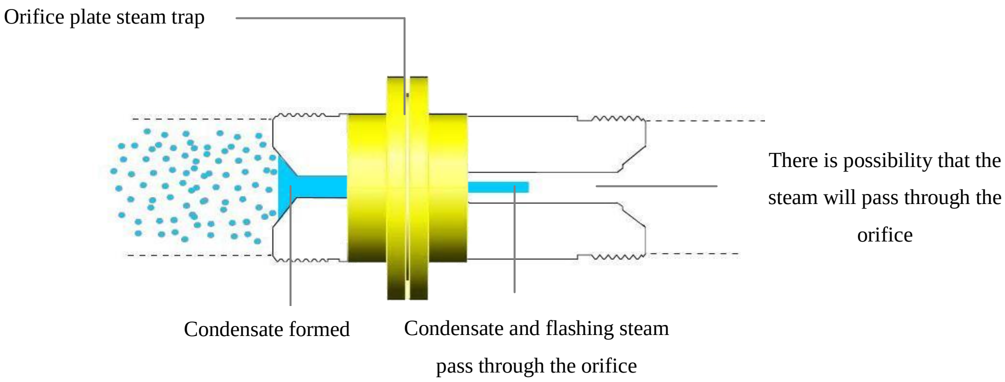

Figure 4.7: Orifice plate steam trap situation during less condensate formed

It is impossible to keep pressure and temperature for a steam system to keep constant all the time. Any change in pressure and temperature of steam system will change the condensate load rate and sometime it can go below than the optimum condensate load. This is what happen when the cooling water flowrate is regulates to be less than 10 L/s. From Figure 4.2, for steam trap with size of 4.0 mm, the steam starts to escape in a big amount for a condensate less than 260 kg/hr. What happen was there is no enough condensate that acts as sealing that can prevent the passage of steam through the orifice as shown in Figure 4.6. This can be seen through the lesser amount of condensate collected inside condensate bucket for the same amount of steam flowrate from steam main pipelines. Thus when the orifice is not properly sized especially when the condensate load is lesser than the orifice size that it should be, the more the amount of the steam will escape. This amount will keep increasing as the condensate load becomes lesser.

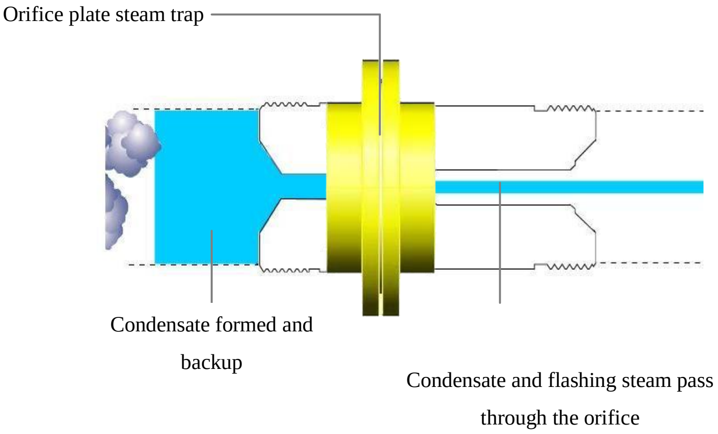

Figure 4.8: Orifice plate steam trap situation during high condensate formed

When there is too much condensate load, condensate backup can occur as shown in Figure 4.7. What will happen is that the efficiency of the heat exchanger will decrease. This happen for orifice size of 4.0 mm and 4.5 mm when the condensate load is bigger than the optimum condensate load of that particular size of orifice. Unfortunately, the effect was unable to be seen in the experiment due to some technical issues.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.0 Conclusions

Based on the result, it can be concluded that the fixed orifice plate steam trap is only best suited for a fixed steam system condition. Different size of orifice will have different set of operation. It undeniable that orifice plate steam trap has no moving part that can malfunction however as shown in Figures 4.1 to 4.6, there will always steam escape through the orifice. This is because the opening of the orifice cannot be modified to limit the mass flow rate through orifice. Based on observation, below is the description on performance of the orifice plate steam trap under various operating condition:

- A proper sizing of orifice plate steam trap is needed to ensure all of the condensate produced by a piece of equipment flows through the orifice. If this condition were achieved, the mass flow rate through the orifice is sufficient to keep condensate from backing up and live steam from escaping. Different size of orifice has different set of operation. This can be verified from figure where the ideal condition load of orifice for 4.0 mm orifice is 260 kg/hr; 5.0mm fixed orifice is 275 kg/hr while 5.0 mm orifice is 290 kg/hr. However, in real life, a constant set of operating condition is hard to achieve. Temperature changes and pressure variations, as well as system demand, directly influence condensate formation and flow. The optimum services of fixed orifice steam trap can only be achieved it is sizing correctly based on condensate load applied and the pressure difference across the plate and condensate load remain constant
- As the regulating valve is adjusted, the condensate flowrate change and the sizing of the orifice is no longer match to the condensate load. This occur when there is less condensate present, live steam escape through the orifice thereby wasting energy and reducing the overall efficiency of the system.

5.1 Recommendations

When determining the orifice size, a designer has to select a small enough orifice to keep too much live steam from escaping and a large enough orifice to keep condensate from backing up. Selecting the proper orifice size for a particular application can be an iterative engineering effort that involves mathematical equations based on scientific principle. The primary reasons for considering an orifice plate steam trap include its simple design with no moving parts and its relatively long service life with little or no required maintenance. The major reasons of why orifice plate steam traps should not be considered include it inability to handle variations in condensate loads and inconsistency of pressure of the steam system as well as it inability to keep live steam from flowing when little or no condensate is present.

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APPENDICES

APPENDIX 1

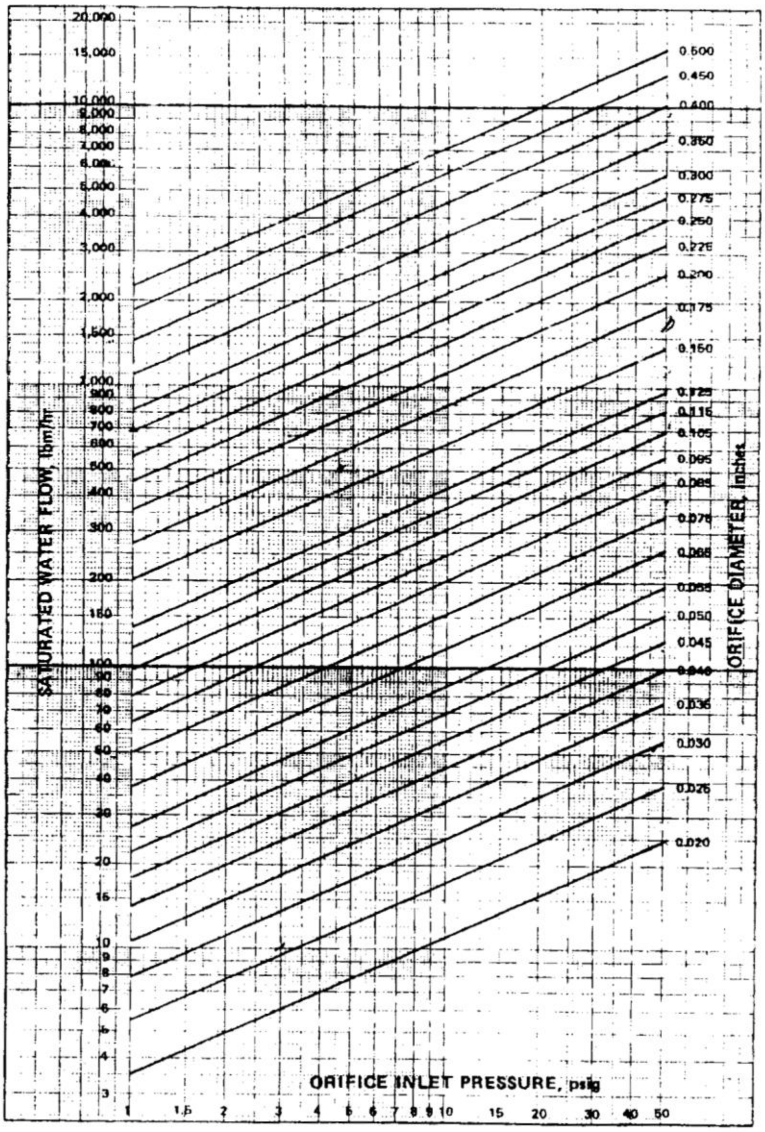

Figure A1: Condensate Flow, 1 to 50 psig, Orifice Capacity for Saturated Water

(*The Steam Trap Handbook*, The Fairmont Press, Inc., Liburn, Georgia, 1995, pg 221)

APPENDIX 2

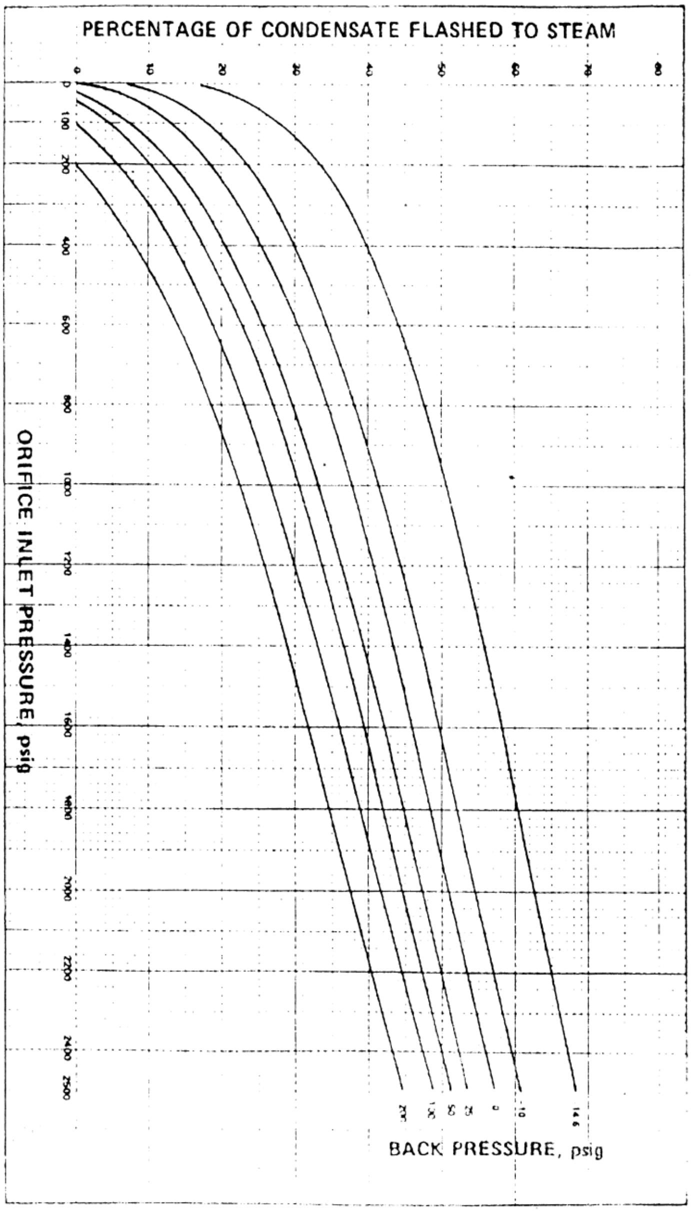

Figure A2: Percentage of flashing steam formed when discharging saturated condensate to a lower pressure (*The Steam Trap Handbook*, The Fairmont Press, Inc., Liburn, Georgia, 1995, pg 223)

APPENDIX 3

Table A1: Milestone for the Final Year Project

No.	Detail/ Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Selection of Project Topic	🟨	🟨													
2	Preliminary Research Work		🟨	🟨	🟨											
3	Submission of Preliminary Report				*											
4	Seminar 1 (optional)					🟨	🟨	🟨								
5	Project Work (Research Stage)					🟨	🟨	🟨								
6	Submission of Progress Report									*						
7	Seminar 2 (compulsory)										🟨	🟨	🟨	🟨		
8	Project work continues (Experiment designing stage)									🟨	🟨	🟨	🟨	🟨		
9	Submission of Interim Report Final Draft														*	
10	Oral Presentation															*

* Milestone

🟨 Process

No.	Detail/ Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Project Work Continue (Experiment designing stage)	🟨	🟨	🟨												
2	Submission of Progress				*											
3	Project Work Continue				🟨	🟨	🟨	🟨		🟨	🟨					
4	Submission of Progress									*						
5	Seminar (compulsory)										🟨	🟨	🟨			
5	Project work continue (Experiment)												🟨	🟨		
6	Poster Exhibition											*				
7	Submission of Dissertation (soft bound)														*	
8	Oral Presentation														*	
9	Submission of Project Dissertation (Hard Bound)															*

*	Milestone
🟨	Process