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ARTICLE

Reducing Energy Losses of Steam Boilers Caused by Blowdown with Using the FMEA Method

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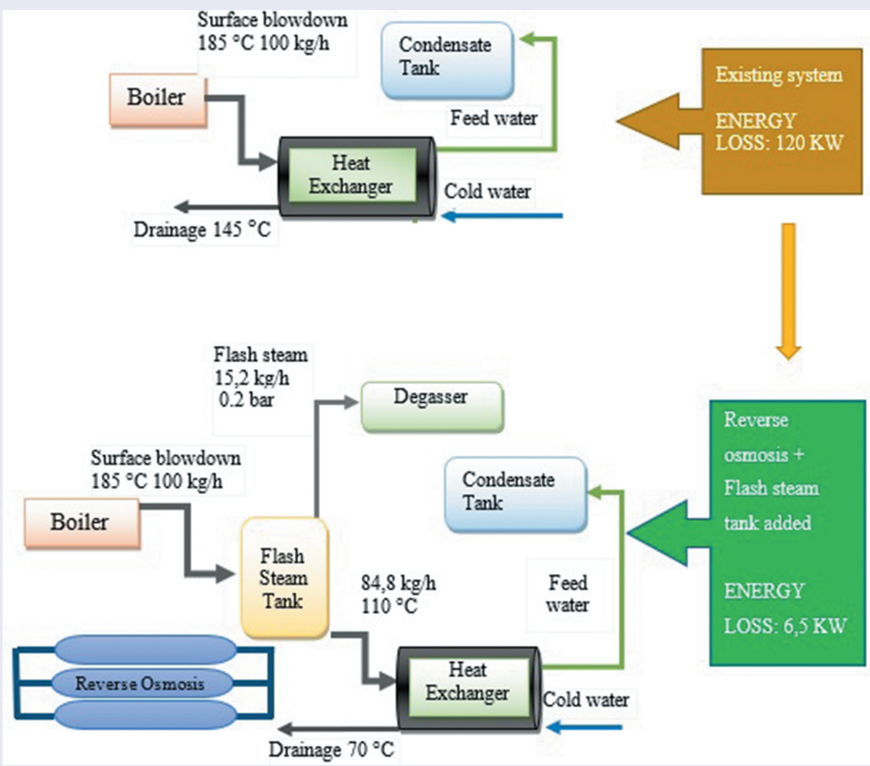
ABSTRACT
In this study, the boiler blowdown was systematically examined and, the risks that increase the energy loss was determined using the potential Failure Mode and Effects Analysis (FMEA) method. Risk priority numbers (RPN) were calculated for each potential risk. It was revealed that 'Performing more blowdown than it is necessary' has the highest priority score. Improvement opportunities were identified by using the tree diagram, which is one of the process improvement techniques. Three suggestions were developed, such as flash steam heat recovery, reduction of water conductivity using the reverse osmosis technique, and the use of both methods. Repayment periods were calculated for each investment. If the flash steam unit and reverse osmosis system are applied together, 113.5 KW/h energy can be saved. It has been demonstrated that the FMEA technique can be used in the investigation and reduction of energy loss.



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1. Introduction

The water in the steam boiler is not entirely pure because it contains solid particles. Therefore, the feedwater has chemically treated before taken into the boiler. Solids dissolved in boiler water are called TDS (Total Dissolved Solids). As evaporation continues, the TDS concentration and water conductivity increase, especially in the region close to the water surface. When the upper limit

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conductivity, which is determined by the boiler manufacturers, is exceeded, foaming begins on the water surface. The foam layer makes evaporation difficult, prevents heat transfer, and shortens the life of the system [1].

Solid materials must be removed from the water to keep the boiler water conductivity within the desired limits. The process of removing these substances from the boiler is called 'Boiler Blowdown'. Instead of the high concentrated water, fresh feedwater is taken into the boiler. Thus, the concentration of solid matter in the boiler is controlled. In terms of the efficiency of the steam system, the blowdown has two important drawbacks. Firstly, during the blowdown process, chemically treated feedwater is taken to the boiler. However, this application will increase production costs. Secondly, although the condensate temperature is generally around 70–80 ° C, the feedwater is 10–20 ° C. Therefore, a significant amount of heat energy is lost for the feedwater heating process [2].

When the literature reviewed, some studies were found investigating the boiler blowdown. Bahadori and Vuthaluru [3] formulated an easier predictive tool than current approaches to reach an appropriate estimate of the blowdown percentage. They calculated the percentage of heat that can be recovered from the flash tank and the heat exchanger system. Vandani et al. [4] investigated the effect of blowdown heat recovery on the energy efficiency. The results showed that the flash tank could increase the system's energy efficiency from 31.68% to 31.91%. Sabzpooshani et al. [5] proposed and evaluated a new modification for a steam plant based on reuse of water blowdown from the boiler. The results showed greater energy efficiency when using a flash tank in the heat exchangers, especially considering water blowdown. Sunudas and Prince [6] conducted the experimental analysis in 10 textile industries located in India and compared the blowdown rates. They aimed to avoid wastage by optimizing the blowdown in the boiler and maximizing the heat recovery from the blowdown. Arunkumar et al. [7] investigated the heat recovery from flash steam in a steam generator. They calculated the amount of blowdown energy recovery and energy saving in the deaerator. İbrahim et al. [8] proposed an automatic control system with a novel electronic circuit to control the surface blow-down process by measuring the concentrations of dissolved solids in the boiler water. They specified that this system reduces the indirect losses and also improves the efficiency of the boiler system. Ranaraja et al. [9] focused on energy losses in the boiler, such as flue gas losses, feedwater losses, radiation losses, and blowdown losses. They described some methods to minimize these losses and to extend boiler energy efficiency. Saha et al. [10] carried out their research focusing on steam systems used in garments industries. The opportunities as flue gas control, boiler load management, blowdown management, insulation of the boiler shell figured out to decrease heat loss. Chauhan and Khanam [11] proposed six different energy integration options for the thermal power plant, including a new retrofit design for boiler blowdown. They carried out detailed design and economic analyses for all these options. Barma et al. [12] gathered studies investigating the causes of heat loss and energy-saving opportunities in the steam generation system. They stated that the heat loss in the boiler occurs in various ways: flue gas loss, radiation and convection loss, short cycle loss, blowdown loss, loss due to moisture in the fuel and incomplete combustion. Huang et al. [13] proposed a new method of water desalination to compensate water loss from boiler blowdown. The reverse osmosis unit and thermal membrane distillation unit are used together in the method they recommend. Azami et al. [14] showed the energy losses of the boiler on the energy flow diagram. They figured out that the boiler energy efficiency gradually decreased from 77.9 to 74.5% as the blowdown rate increased from 0.5 to 5.0%. Tanasić et al. [15] have experimentally investigated the combustion process to improve the energy efficiency of an industrial steam boiler. As a result of the study, they proposed five improvements and, one of these measures is the application of automatic blowdown and water desalting. Cortes-Rodríguez et al. [16] determined the energy losses in six different boilers using the first law of thermodynamics and showed them on the Sankey diagram. They calculated the share of the blowdown loss. Gupta et al. [17] stated that low boiler efficiency resulted from various heat losses such as loss due to unburned carbon in refuse, loss due to dry flue gas, loss of moisture in fuel, loss due to radiation, loss due to blowdown and loss due to incomplete combustion. Charde et al. [18] explained in detail the factors affecting the performance of a steam boiler used in a thermal power plant and the main energy losses in the boiler. They suggested the use of automatic blowdown equipment.

The factors that increase blowdown must first be determined to reduce the energy loss in the boilers. Failure modes, effects and analysis (FMEA) is a method commonly used to evaluate product quality risks in production or equipment failures in the field of maintenance. This method can also be used in identifying, evaluating, and prioritizing the risks that decrease energy efficiency.

When previous studies using the FMEA technique for boilers searched, some investigations were encountered. But these studies use this technique only to analyze the safety and operational risks but not energy risks. Some of them are as follows: Ahmed and Gu [19] examined a marine boiler potential failure mode and the system's operational difficulties using the failure modes, effects, and criticality analysis (FMECA) technique. They focused on the thirteen noteworthy marine accidents which cause an explosion, fire, blackout, and severe operational disruption problems.

Putra and Purba [20] analyzed the frequent failures in the boiler of a steam power plant. They created cause and effect diagram to find out boiler failures and their effects and then calculated risk priority numbers of these. Mariajayaprakash and Senthilvelan [21] identified the failures which frequently occurred in the cogeneration boiler and gave the solution to minimize these failures by using the Ishikawa diagram and failure mode and effect analysis. Afefy [22] performed failure mode and effect analysis (FMEA) for a fire-tube boiler in the process steam plant. He examined malfunctions in various boiler equipment and their effects. Igboanugo et al. [23] carried out the FMEA for critical components of the boiler system. They highlighted the various ways by which the system can fail and the impact of such failures on the entire boiler system performance. Erajati et al. [24] researched equipment risks on the boiler using the FMEA method and obtained 3 top events as the high-risk category. Kumar et al. [25] applied the FMEA method to the water tubes in the boilers. They determined that there are many critical failure modes in the boiler and focused on failures occurring in the water tubes and then, they calculated the risk priority coefficients.

In the current study, the FMEA technique was used to assess the energy loss that occurs during the boiler blowdown process. This study is valuable because, to our knowledge, no systematic and risk-based study presents the blowdown loss in the boiler. As a novelty; FMEA, which is one of the quality improvement tools, was used for the first time by adapting it to the energy field. For the energy risks with high-risk priorities, improvement suggestions were proposed to the extent of today's technological possibilities.

2. Materials and Methods

2.1. Potential Failure Mode Effects and Analysis (FMEA)

FMEA is an analysis technique carried out to prevent all types of design and process originated failure that may occur in a product. All kinds of errors/failures are analyzed according to the possible effects on the customer. All these analyzes are carried out before the product is placed on the market and even during the design and trial production. FMEA is a powerful technique that prevents potential errors before they occur.

The method consists of four steps: a critical examination of the system, identification of factors that may cause the failure, determining the hazards caused by the failure, and grading the consequences of each potential failure. When analyzing failures with FMEA, three indicators have taken into account. These:

Occurrence: Frequency of failure

Severity: Impact level of failure

Detection: Detectability of failure

The risk priority number (RPN) is the combined effect of the three factors, which is calculated by multiplying the occurrence, severity, and detection scores. When applying the FMEA method, the criticality of each possible failure is determined based on RPN [26].

Risk Priority Number (RPN) = Occurrence x Severity x Detection

The occurrence, severity, and detection indicators are scored on a scale of 1 (Best) to 10 (Worst). Product and maintenance-oriented FMEA rating tables are adapted with the energy field for this study and are shown in Table 1.

The RPN vary from 1 to 1000 since they take values from 1 to 10. Corrective or preventive actions are recommended for all failures, starting with the highest Risk priority number to pull RPN towards 1 [29]. This technique plays a significant role in determining which failure should be the starting point for improvement. In Table 2, the evaluation scale regarding the RPN is given [30].

Table 1. Energy FMEA rating table (adapted from Suresh et al. [27] and Dieter and Schmidt [28]).

Occurrence	Score	Severity	Score	Detection	Score
Extremely high occurrence	10	Hazardous, Very high energy loss without warning	10	No chance to detect energy loss	10
Very high occurrence	9	Critical effect, Very high energy loss with warning	9	Very remote chance to detect energy loss	9
High occurrence	8	Extreme effect, Very high energy loss	8	Remote chance to detect energy loss	8
Frequent occurrence	7	Major effect, high energy loss	7	Slight chance to detect energy loss	7
Moderate occurrence	6	Significant effect, moderate energy loss	6	Low chance to detect energy loss	6
Occasional occurrence	5	Moderate effect, low energy loss	5	Moderate chance to detect energy loss	5
Slight chance of occurrence	4	Slight effect, Very low energy loss	4	Moderately high chance to detect energy loss	4
Very slight chance of occurrence	3	Slight effect, Minor energy loss	3	High chance to detect energy loss	3
Remote	2	Very Slight effect, Very Minor energy loss	2	Very high chance to detect energy loss	2
Extremely remote	1	Unnoticeable effect, none energy loss	1	Almost certain to detect energy loss	1

Table 2. RPN evaluation scale.

RPN	Evaluation
RPN 40	No need to take action
40 ≤ RPN ≤ 100	Precaution can be taken
RPN 100	Precaution must be taken strictly

2.2. Tree Diagram

A tree diagram is a planning tool that shows the hierarchy of tasks and subtasks to complete. The tree diagram begins with an item that branches into two or more parts. The finished diagram looks like a tree with multiple branches. It can be used for different purposes as analyzing processes in detail, getting the root cause of a problem, and identify actions to carry out the solution [31]. There are three different ways to use this diagram: why-why tree diagram, why-how tree diagram, and how-how tree diagram. Shematic view of diagram is shown in Figure 1.

Once it has discovered why a problem occurred, it is necessary to find a permanent solution to the problem. How-How tree diagram is a tool that is useful in creating a practical solution to a problem. It works by repeatedly asking: "How can the problem be solved? " It continues to ask 'How' until there are no other answers or are satisfied with the ideas for improvement [32].

2.3. Calculation of Boiler Blowdown Loss

Since the water in the boiler evaporates, the conductivity increases continuously near the water surface. Therefore, the conductivity of the water should have checked regularly, and then the required blowdown should have done accordingly. Some energy is being lost during the discharging of the high-temperature boiler water. For this reason, blowdown should have done as much and as required. In the case of excessive blowdown, more energy will be used in the heating process of feedwater, and the feedwater chemicals will cause an additional cost [1,33].

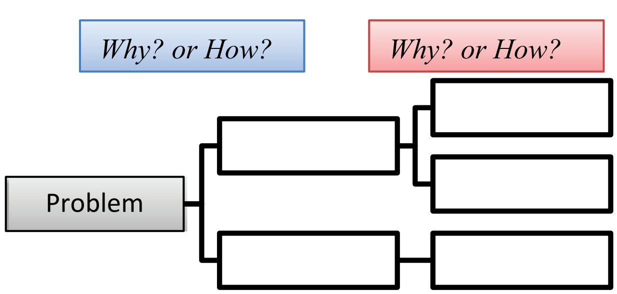

Figure 1. Tree diagram.

During the blowdown, depending on the feature of the water, there is energy loss between 1 . . . 3%. When the blowdown operations have performed in optimum conditions, energy losses can have brought to 0,3–1% depending on the operating pressure and feedwater conductivity [1]. The amount of boiler blowdown to be performed can be calculated as the following formula [33]:

$$m_{blowdown} = F^{*}\ S/(B\text{-}F) \quad (1)$$

3. Results and Discussions

3.1. The Blowdown Energy Loss in the Factory

In this research work, observations were realized in a textile factory, which has a 5 ton/hour capacity steam boiler used for the distillation process. In the current system, the surface blowdown process is carried out automatically. Some of the blowdown waste heat is recovered through a heat exchanger. There is also an automatic bottom blowdown system in the boiler to ensure unattended operating conditions for 72 hours.

The conductivity of the feedwater and boiler water should be known to calculate the amount of water discharged through the blowdown. The well water with a conductivity of 673 µS/cm is used as feedwater in the factory. The boiler water conductivity has automatically set to 5500 µS/cm, which is very close to the limit value defined by EN 12,953–10.

The amount of blowdown performed in the current system was calculated using Equation (1) as follows:

Operating pressure = 10 bar

$h_{water@10bar} = 781$ kj/kg

S = 5000 kg/h

F = 673 µS/cm

B = 5500 µS/cm

$m_{blowdown} = 5000 * 673/(5500–673) = 697$ kg/h

Heat lost with the surface blowdown can be calculated as follows:

$$Q_{blowdown\ loss} = m_{blowdown} \times h_{water@10bar} \quad (2)$$

$$Q_{blowdown\ loss} = 697 \times 781 = 544{,}357\ \text{kJ/h} = 152\ \text{KW}$$

Before the blowdown was sent to the drainage, some of its energy was being recovered by a heat exchanger. The blowdown water entering the heat exchanger with a flow rate of 697 kg/h and a temperature of 185 °C is exiting from the heat exchanger at 145 °C. The energy savings achieved with recovery has been calculated as follows:

$$Q_{Recovered} = m_{blowdown}\ C_p\ (T_{in}\text{-}T_{out}) \quad (3)$$

$Q_{Recovered} = 697 * 1 * (185–145) = 27\ 880$ kcal/h = 32 KW 32 KW of the energy has recovered. The net blowdown energy loss, in this case, is as follows:

$$Q_{net\ blowdown\ loss} = Q_{blowdown} - Q_{recovered} \quad (4)$$

$$Q_{net\ blowdown\ loss} = 152–32 = 120\ KW$$

3.2. Energy FMEA for Blowdown Loss

Energy FMEA was carried out to reduce the blowdown energy loss in the steam boiler. In this regard, the risks leading to blowdown loss was determined by evaluating the technical staff of the company and the comprehensive literature review. The causes and effects of each risk have been identified. The severity, the probability of occurrence, and detectability of each risk were scored using a scale of 1–10. Risk priority numbers were calculated for each risk. According to the FMEA table given in Table 3, 'Performing more blowdown than it is necessary' is found as the risk with the highest risk priority score. The improvement suggestions to prevent this failure were determined using the how-how tree diagram in Figure 2.

In the tree diagram, two different methods were proposed in response to the question of how we can reduce the blowdown loss. One of these is heat recovery. In the current system, the blowdown heat is recovered with a heat exchanger. It is possible to benefit more from the energy of the blowdown by adding a flash steam tank to the system. Another method is reducing the amount of blowdown. The blowdown is already carried out automatically. The well water is used as feedwater in the company and is given to the boiler through softening units, but it still has a high conductivity. For this reason, the reverse osmosis system should be added to the softening system, and thus feedwater conductivity should be further reduced. Below, three suggestions have presented to reduce blowdown energy loss.

1. Improvement Suggestion: Some of the water discharged by blowdown turns into steam as a result of pressure drop. This steam is called *flash steam* that carries a large amount of heat. Flash steam can be recovered by adding a flash steam unit to the boiler blowdown outlet. The recovered flash steam can be used in degasser.

The pressure of the flash steam unit is usually around 0,2 bar. When the saturated water expands from 10 bar to 0,2 bar, some of it turns into flash steam. The amount of produced flash steam can be calculated as follows:

$$H_{steam@0,2bar} = 2683,4 \text{ kj/kg}$$

$$h_{water@0,2bar} = 438,9 \text{ kj/kg}$$

$$\%\ \text{Flash Steam} = \frac{h_{water@10bar} - h_{water@0,2bar}}{h_{steam@0,2bar} - h_{water@0,2bar}} \quad (5)$$

$$\%\ \text{Flash Steam} = \frac{781 - 438,9}{2683,4 - 438,9} * 100 = \%15,2$$

The amount of flash steam gained from the surface blowdown was calculated as follows:

$$m_{flash\ stream} = m_{blowdown} * \%\ 15,2$$

$$m_{flash\ stream} = 697 \times 0,152 = 106,3 \text{ kg/h}$$

If the remaining water in the flash steam tank is drained as saturated water at 0,2 bar, the energy lost can be calculated as follows:

$$m_{condensate}: m_{blowdown} - m_{flash\ steam} \quad (6)$$

$$m_{condensate} = 697–106,3 = 590,7 \text{ kg/h}$$

$$Q_{blowdown\ loss} = m_{condensate} * h_{water@0,2\ bar} \quad (7)$$

$$Q_{blowdown\ loss} = 590,7 * 438,9 = 259\ 273 \text{ kJ/h} = 72\ KW$$

The liquid remaining in the flash steam tank can be evaluated for heating the feedwater. In this way, some more energy can be recovered. If the liquid remaining in the tank enters the heat exchanger at 110 °C and exits at 70 °C as shown in Figure 3, the savings can be calculated as follows:

$$Q_{recovered} = m_{condensate}\ C_p\ (T_{in}\text{-}T_{out}) \quad (8)$$

$Q_{recovered} = 590,7 * 1 * (110–70) = 23\ 628$ kcal/h = 27 KW

Thus, 27 KW of the energy has recovered. The net blowdown loss, in this case, has calculated using Equation (4) as follows:

$$Q_{net\ blowdown\ loss} = 72–27 = 45\ KW$$

2. Improvement Suggestion: The amount of boiler blowdown is proportional to the quality of feedwater. If the feedwater conductivity is high, the blowdown rate will also be high. Water conductivity can be reduced with the reverse osmosis technique. Thus, less blowdown can be achieved, and the energy efficiency of the boiler operated with low conductivity water will increase considerably. In the facility, there is a feedwater softening system to prevent over blowdown. In addition to softening, the reverse osmosis system can also be added. In this way, the amount of blowdown will be reduced, and a significant amount of energy can be maintained. When using the reverse osmosis technique, feedwater conductivity is expected to decrease to 10 µS. In this case, blowdown loss can be calculated using Equation (1) as follows:

$$m_{blowdown}: = 5000*10/(5500 - 10) = 9 \text{ kg/h}$$

Although the amount of blowdown has calculated as 9 kg/h in practice, it has recommended performing blow down at least a 2% steam capacity [1].

$$S = 5000 \text{ kg/h}$$

$$m_{blowdown} = 5000 * 0,02 = 100 \text{ kg/h}$$

$$Q_{blowdown\ loss} = m_{blowdown} \times h_{water@10bar}$$

$$Q_{blowdown\ loss} = 100 \times 781 = 78\ 100 \text{ kJ/h} = 47\ KW$$

The discharged blowdown water can still be used to heat the feedwater. If the blowdown that enters the heat exchanger at a flow rate of 100 kg/h and a temperature

Table 3. Boiler blowdown loss Energy FMEA.

Energy Failure Mode and Effects Analysis (FMEA)								
Process	**Potential Failure mode for Energy**	**Potential Failure Causes**	**Potential Failure Effects**	**Precaution, Current controls**	**Severity**	**Occurrence**	**Detection**	**RPN**
Steam Production	Performing more blowdown than it is necessary	Improper blowdown setting, high conductivity of feedwater	Over-blowdown leads to high energy losses. Fuel and chemical consumption increase.	An automatic blowdown system is available. Water softening system is used. Some of the heat has been recovering by a heat exchanger.	8	5	4	160
	Feedwater features are not good enough	Dissolved oxygen and carbon dioxide gases in the feedwater	It causes corrosion on boiler surfaces.	Water has been degassing with the degasser.	6	1	2	12
		Organic substances, TDS concentration rises above the allowable limit	It causes foaming. Steam quality decreases, and process times increase.	An automatic blowdown system is available. The particles are removed by the boiler chemicals and softening system.	6	3	4	72
		Salts	It causes the formation of a boiler stone. Both heat conduction and boiler efficiency will decrease.		6	3	4	72
		High conductivity of feedwater	It causes the boiler blowdown to be made more frequently and reduces boiler efficiency.	Water softening system is used.	7	5	3	105

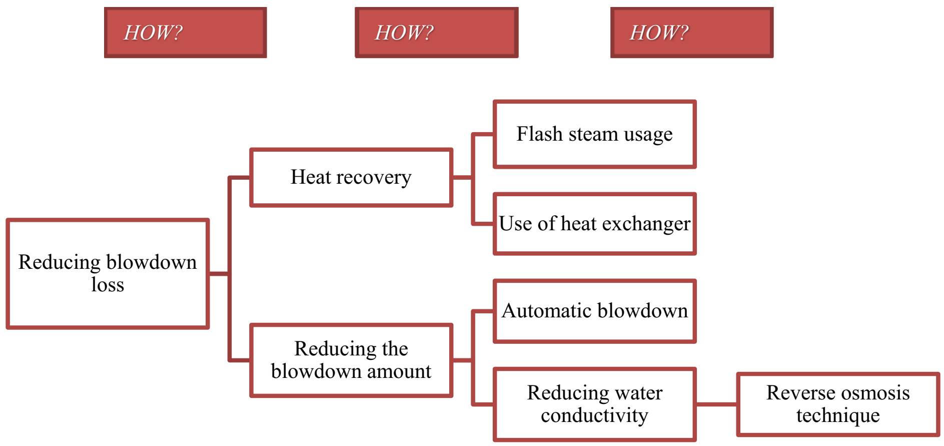

Figure 2. How-how tree diagram.

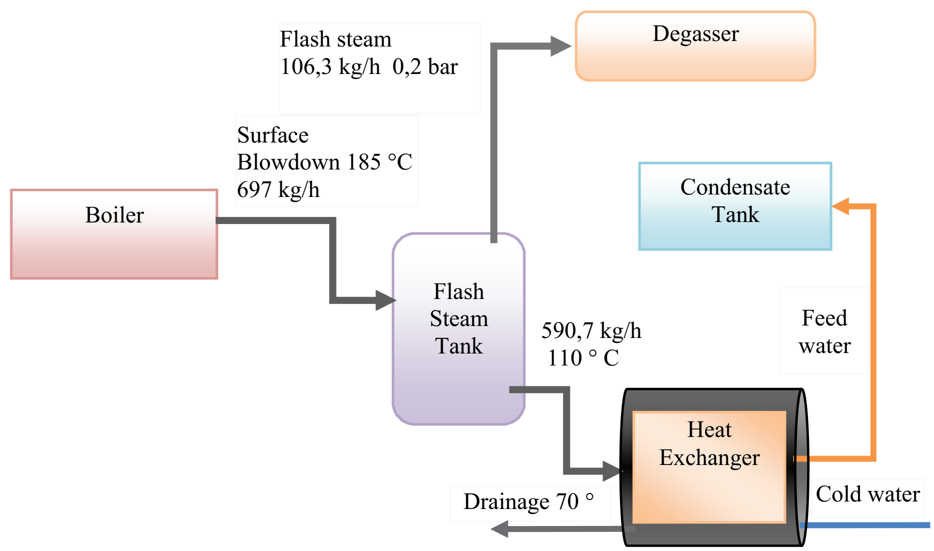

Figure 3. Boiler blowdown system with flash steam tank added.

of 185 °C, exits at 145 °C from the heat exchanger as shown in Figure 4, energy-saving is calculated using Equation (3): as follows:

$Q_{\text{recovered}} = m_{\text{blowdown}}\, C_p\, (T_{in}\text{-}T_{out})$

$Q_{\text{recovered}} = 100 * 1 * (185–145) = 4\ 000$ kcal/h = 4,6 KW

Thus, 4,6 KW of the energy has also recovered. The net blowdown loss, in this case, calculated using Equation (4) as follows:

$Q_{\text{net blowdown loss}} = 47–4{,}6 = 42{,}4$ KW

3. Improvement Suggestion: Both the flash steam unit and reverse osmosis system can be added. After purifying water with reverse osmosis, some more energy can be recovered with the flash steam tank. The recovered flash steam can be used in degasser. When the blowdown has reduced to 100 kg/h, the amount of flash steam is as follows:

% Flash steam = $\frac{781{,}1-438{,}9}{2683{,}4-438{,}9} * 100 =$ %15,2

$m_{\text{blowdown}} = 100$ kg/h

$m_{\text{flash steam}} = 100 \text{ x } 0{,}152 = 15{,}2$ kg/h

$m_{\text{condensate}} = 100–15{,}2 = 84{,}8$ kg/h

The remaining blowdown water has drained as saturated water at 0,2 bar; the energy lost can be calculated using Equation (7) as follows:

$Q_{\text{blowdown loss}} = 84{,}8 * 438{,}9 = 37\ 174$ kj/h = 10,3 KW

The remaining water in the flash steam tank can be used to heat the feedwater by passing it through the heat exchanger. If the liquid remaining in the tank enters the

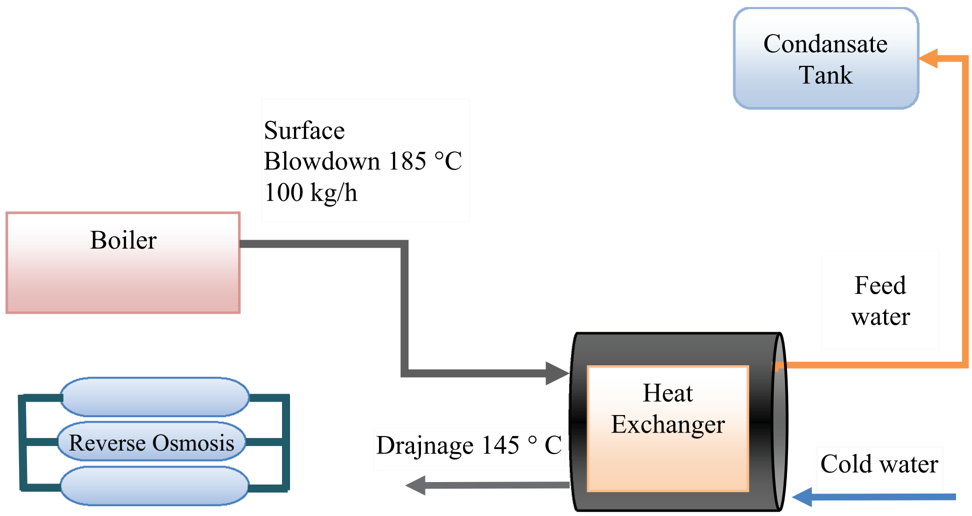

Figure 4. Boiler blowdown system with a reverse osmosis unit.

heat exchanger at 110 °C and exits at 70 °C, the savings to be obtained can be calculated using Equation (8) as follows:

$Q_{recovered}$ = 84,8 * 1 * (110–70) = 3 392 kcal/h = 3,8 KW

Thus, 3,8 KW of the energy has recovered. The net blowdown loss, in this case, calculated using Equation (4) as follows:

$Q_{net\ blowdown\ loss}$ = 10,3–3,8 = 6,5 KW

The savings for the proposed improvement suggestions and the payback periods of the investments are given in Table 4. In the current system, the blowdown (697 kg) is performed by about 14% of steam capacity (5000 kg). By using the reverse osmosis technique, the required amount of blowdown can be reduced from 697 kg/h to 100 kg/h. If the flash steam unit has also added, approximately 15.2% of the blowdown can be recovered as flash steam. When the flash steam system and reverse osmosis system are applied together, 113,5 KW hourly gain can be achieved. If the steam boiler operates 5760 hours a year, the system will amortize itself in 19 months.

4. Conclusion and Future Work

In the current study, the energy loss caused by the boiler blowdown process has been investigated. FMEA technique has used to identify potential energy loss risks and prioritize them. The risk with the highest risk priority score has been determined as ‘ performing more blowdown than it is necessary.’ Then, suggestions to reduce this risk have investigated using a how-how tree diagram.

According to the tree diagram, three suggestions have developed: ‘flash steam heat recovery, reduction of water conductivity by using reverse osmosis technique, and using both methods.’ Possible blowdown losses have been calculated, and a schematic view of the boiler blowdown system has given for each suggestion. It has been observed that the highest savings can be achieved when flash steam heat recovery and reverse osmosis techniques are applied together. Thus, the blowdown loss of 120 KW can be reduced to 6.5 KW. In other words, Blowdown-induced energy loss will decrease by 94.6%. The investment will be able to repay itself within 19 months. After this period, the company will save approximately 18,826 USD each year.

FMEA is a never-ending study, and as the current technologies and possibilities progress, these improvements should be incorporated into the system and, the FMEA study should be updated accordingly. In future studies, other energy losses in the boiler can be investigated with the FMEA technique. Also, the research method described here can be applied to other energy-using

Table 4. Savings and payback periods of improvement suggestions.

	Energy Loss	Saving (KW)	Savings ($/year)	Investment Pay ($)	Payback Period (months)
Current system	120 KW	-		-	-
1. Suggestion: Flash steam unit (225 kg/h)	45 KW	75	11,604	7786	8
2. Suggestion: Reverse Osmosis Unit (5 ton)	42,4 KW	77,6	13,272	22,635	20
3. Suggestion: Flash steam unit + Reverse Osmosis Unit	6,5 KW	113,5	18,826	30,421	19

processes and equipment.

Nomenclature

S: Steam capacity (kg/h)
F: TDS in feedwater (µs/cm or ppm)
B: Maximum permissible limit of TDS in boiler water (µs/cm or ppm)
$h_{water@10bar}$: The enthalpy of saturated water at 10 Bar
$H_{steam@0,2bar}$: The enthalpy of steam at 0,2 Bar
$h_{water@0,2bar}$: The enthalpy of saturated water at 0,2 Bar
$m_{blowdown:}$ The amount of surface blowdown (kg/h)
$m_{flash\ stream}$: The amount of flash steam produced in the flash tank (kg/h)
$m_{condensate}$: The amount of condensate formed in the flash tank (kg/h)
C_p: Specific heat (Cal/g °C)
T_{in}: Inlet temperature of fluid (°C)
T_{out}: Outlet temperature of fluid (°C)

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