

Energy Optimization and Steam System Performance Enhancement in Plastic Processing Plant

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Abstract: This study investigates energy optimization opportunities and steam system performance improvement in a plastic processing manufacturing plant located in the Sabahan industrial area of Kuwait. The study was conducted over a six-month period and focused on evaluating boiler operation, steam demand fluctuations, sterilizer loading effects, and waste heat recovery opportunities. Data collection and system analysis were performed with the participation of engineering, maintenance, and production personnel. Several energy-saving measures were identified, including sterilizer startup control, optimization of boiler blowdown total dissolved solids setpoints, and recovery of waste heat from sterilizer cooling processes. The proposed modifications are expected to reduce steam losses, stabilize system pressure, improve boiler efficiency, and lower operational costs. Estimated savings include significant reductions in steam energy consumption and cooling tower electricity use. The findings demonstrate that effective steam system management and heat recovery integration can substantially improve industry.

Keywords: Boiler Efficiency, Steam System Optimization, Energy Management, Waste Heat Recovery, Plastic Processing Plant, Sterilizer

1. Introduction

Most countries have their own standard for designing the boiler and selecting the materials. Different standards will have a direct effect on the price. The quality of boilers is determined based on the manufacturing technique, which also has the impact on boiler production cost. A high-quality boiler can provide a long, low-maintenance life. Many engineering applications that are characterized by high heat fluxes involve boiling and condensation. In a closed-loop power cycle, pressurized liquid is converted to vapor in a boiler [1]. Large plants can save millions of dollars in energy and maintenance costs each year by improving the energy efficiency of their steam or process heating systems. Today's competitive facilities environment increases the importance of optimizing the efficiency of large systems, such as boiler plants.

2. Steam System Description

2.1 Plant Specifications

The plant contains three main boilers, which the plant needs in the production process.

The boilers system runs at an average pressure of 106 psig, and all the boilers are equipped with automatic blowdown set to 1900 μ S and were recently retrofitted with dual-gas burners (LPG and Diesel). Boiler #2 has been recently retrofitted with a new burner with O₂ controls and a VFD blower to increase its efficiency.

Table below shows specification of the three boilers fixed at the plastic processing manufacturing plant indicating name of manufacturer, model, capacity, pressure, and the technology.

2.2 Water Quantity Feeding Supplies

Table 1: Boilers make, models & capacities

| Fuel Used | Natural Gas | Capacity | | | Pressure | | Technology | | | |
|----------------|----------------|--------------|------------|------------------|------------|----------|-----------------------------|------------|--------------------|-----|
| Main Equipment | Manufacturer | Model Number | Max. Rated | Actual Operating | Max. Rated | Setpoint | O ₂ Trim Control | Economizer | Automatic Blowdown | VFD |
| | | | lb/hr | lb/hr | PSig | PSig | | | | |
| Boiler #1 | Cleaver Brooks | CB-600-600 | 25,106 | 6,627 | 250 | 115 | NO | YES | YES | YES |
| Boiler #2 | Cleaver Brooks | CB-600-600 | 25,106 | 10,677 | 250 | 100 | YES | YES | YES | YES |
| Boiler #3 | Hurst | S3000.250.2 | 20,700 | 1,104 | 250 | 105 | NO | NO | YES | NO |

Feeding water from the boilers is a mix between condensate return, sterilizer cycle water, stills blowdown and soft water. The water from the sterilizers goes through an R.O. unit before

going to the deaerator. The chart below shows the composition of the boilers feed water.

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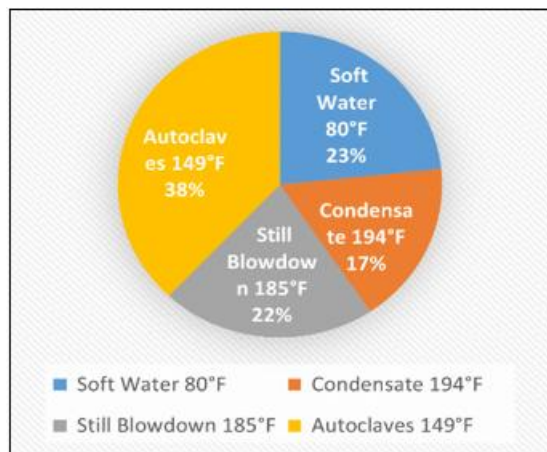


Figure 1: Composition of boilers feed water

2.3 Plastic Processing Manufacturing Plant Layout

The system layout of boilers and its accessories at plant are clearly shown in Figure2.

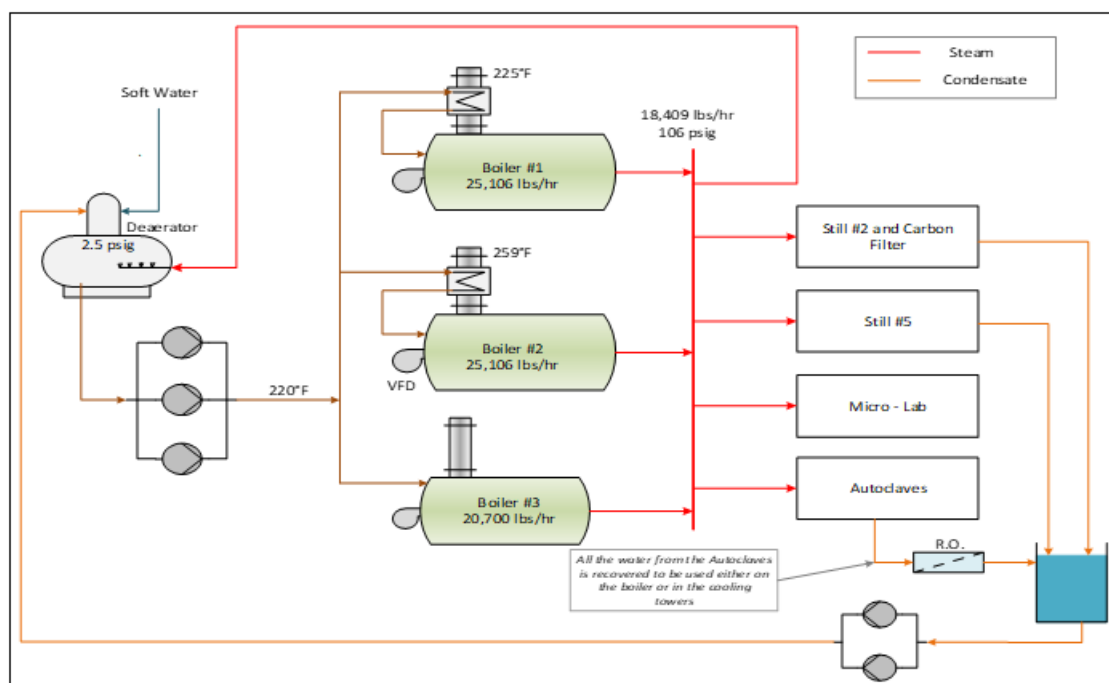


Figure 2: Boiler plant layout

3. System Operation

Steam demand within the facility exhibits significant variation over the course of a typical week as shown in fig 3, reflecting changes in process loading and operational schedules. The average steam consumption is approximately **18,408 lb./hr.**, while peak demand periods reach up to **48,486 lb./hr.**, indicating a wide operating range for the steam generation system. The weekly steam consumption pattern and the corresponding header pressure profile are illustrated in Figure (3), which provides a representative overview of system performance under normal operating conditions. The boiler plant is designed to operate using a pressure-based staging and sequencing strategy. As indicated in Equipment Table (1) at the beginning of this section, specific pressure setpoints have been assigned to each boiler to ensure orderly lead-lag operation. Based on the current configuration, **Boiler No. 2** is designated as the primary (lead) boiler, followed sequentially

by **Boiler No. 1** and then **Boiler No. 3** as additional capacity is required. While the intended control philosophy and sequencing logic are technically sound, actual plant operation does not consistently follow the designed sequence. This deviation is primarily attributed to instrumentation calibration and adjustment inconsistencies among the boilers' pressure sensing devices. At present, the individual boilers do not register identical pressure values at the same system condition, resulting in asynchronous responses. Consequently, Boilers No. 1 and No. 3 are frequently initiated even when the system load does not warrant their operation. This condition leads to unnecessary cycling, reduced operational efficiency, and potential increases in maintenance requirements. The dominant steam consumer within the facility is the sterilization department. The plant is equipped with a total of **17 autoclaves**, consisting of **five (5) two-place units** and **twelve (12) four-place vessels**.

Collectively, the sterilization process accounts for a substantial portion of the overall steam demand. Operational records indicate that the facility completes approximately **25,842 sterilization cycles per year**, distributed as **7,004 cycles** in the two-place autoclaves and **18,838 cycles** in the four- place units. Analysis of cycle types shows that approximately **73%** of all sterilization runs are performed using the “Unvented” cycle configuration, which represents the predominant operating mode for the sterilization process.

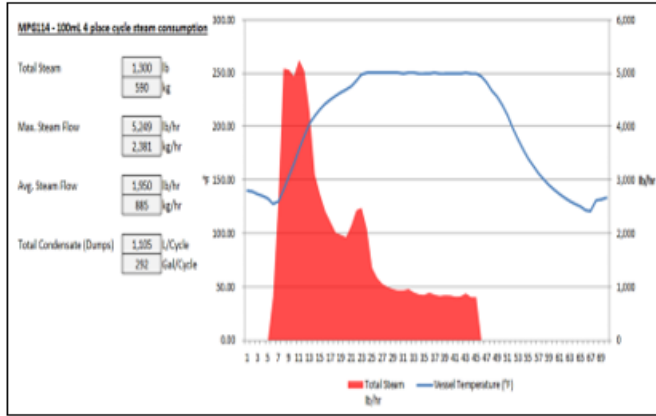


Figure 4: Steam Consumption

Figure (4) shows the steam consumption in an unvented cycle for a 100 mL batch in a 4-place vessel.

As the graph shows, the main steam consumption happens at

the beginning of the cycle, during the “Steam On” phase and no type of control on the number of autoclaves that can start at the same time. Therefore, when too many starts at similar times, they create a pressure drop in the system.

Figure 5 shows steam pressure drop in the steam header compared with the number of places of sterilizers (number of trucks been sterilized) that were on the “Steam On” phase of the cycle on. As seen on the graph of fig. 4, when more than 20 equivalent places (could be 4 4-place plus 2 2-place) are on “Steam On”, a pressure drop down to 75 psig occurs. Also, most of the time that 15 places were on “Steam On”, the pressure in the system dropped to 100 psig or below.

4. Steam System Recommendations

4.1 Reduce Boiler pressure by controlling the sterilizer’s startups!

The system has no control to limit the number of sterilizers that are requiring steam at the same time (start-up of heating). As shown in the previous page, when several sterilizers start at the same time (equivalent to 15-20 places), it creates a pressure drop in the system that affects the boilers and the rest of the sterilizers. To improve this situation, a steam demand controller needs to be installed. This type of system will limit the number of sterilizers requiring steam based on the boilers capacity. This system will stabilize the

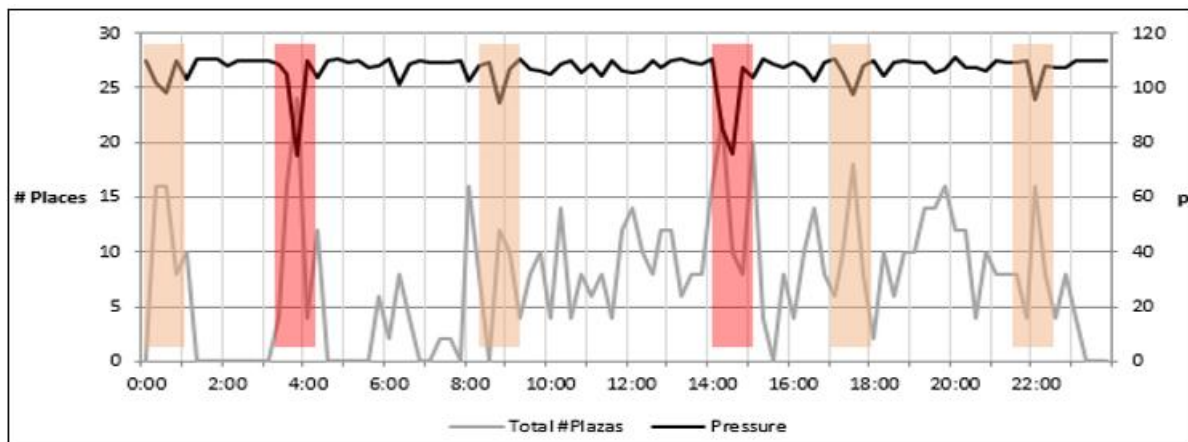
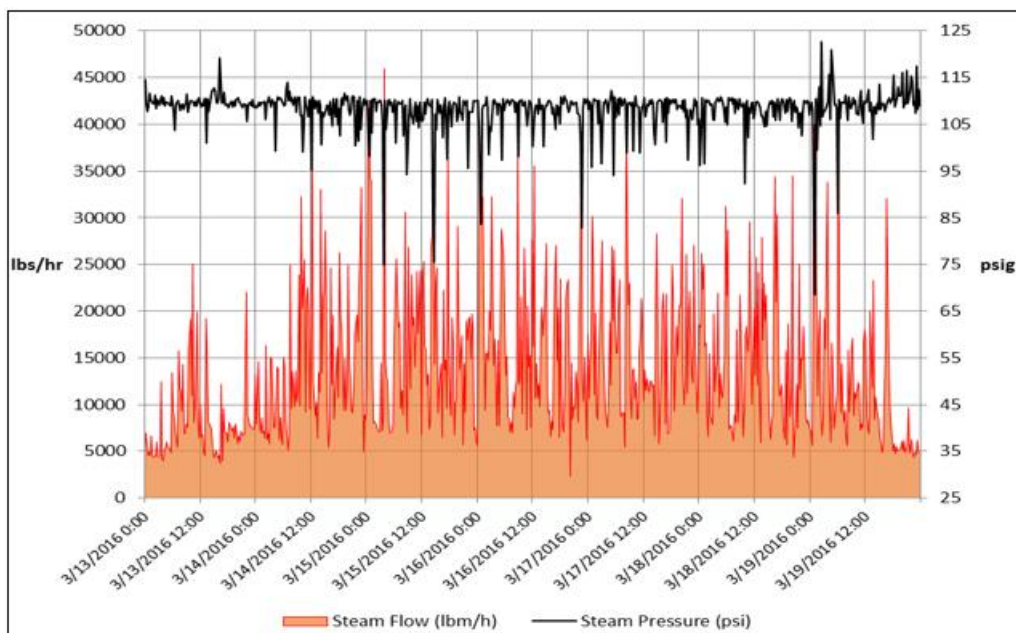


Figure 5: Steam pressure on steam header compared with number of places of sterilizer



steam pressure, and because of this, the boilers can be controlled at a reduced pressure with similar processes run the steam system at 100 psig. To avoid the cycling of the boilers, the controls have been modified so that all the boilers respond to one pressure signal in the supply steam manifold. The estimated cost of the proposed controller is \$30,000.

The following are some of the benefits of controlling the sterilizer’s start-ups to reduce the system’s pressure and control the boilers with one pressure signal:

- Reduction of radiation and convection losses.
- Reduction of blowdown losses.
- Reduction of the LPG required producing steam.
- Reduction of the steam distribution losses.
- Provide the sterilizers with a more stable pressure.
- Reduce problems in the cycle heat ramp because of low steam pressure.

The estimated savings from reducing the steam pressure are:

Table 2: Estimated saving from reducing steam pressure.

| Procedure | Capacity Saving | \$- Saving |
|---|-------------------|--------------|
| Installation of steam demand controller | 1151 MMBTU / YEAR | 16736 / YEAR |

4.2 Increase TDS set point for the Boilers Blowdown

The set point for the automatic blowdown was set at 1900µS. This causes a loss of energy on the exhaust vent of the blowdown tank. Previous studies recommended the set point for the automatic blowdown to be 6000µS. By changing the set point to 6000µS, the boiler, blowdown energy losses reduced by 2,396 MMBTU. During daily site visit, the plant started the increase in the set point, and results were immediate.

4.3 Sterilizer heat recovery in cooling

Sterilization is an extremely energy-intensive process. All of that thermal energy used to raise the temperature of steel vessels, the mass of water inside, and the product from about room temperature to 121°C. When sterilizers go into cooling,

however, a vast majority of that heat transferred to cooling water and sent to the cooling towers, where heat rejected to outside air. A vast amount of thermal energy is wasted. A recommendation was made to recover some of waste heat.

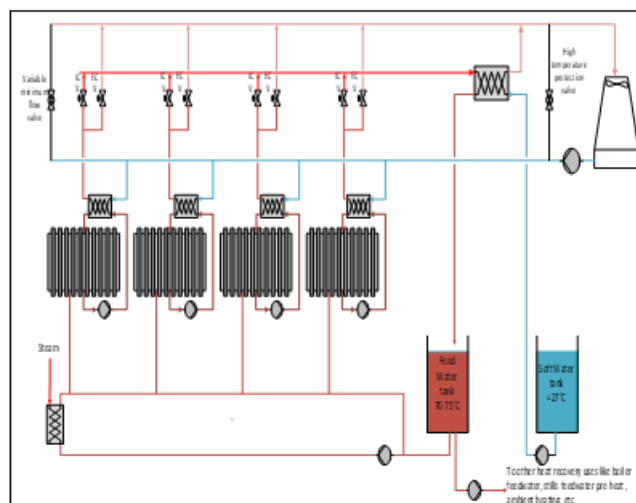


Figure 6: Installation concept to show way to recover waste heat.

Although this diagram does not show the exact installation for typical industry use, it shows the installation concept preferred in the plant. For this system to work, a secondary return pipe to the cooling towers has to be installed; the idea is to send the water from the initial cooling to this pipe and the extended cooling water to the other pipe. The water from the initial cooling will then go through a heat exchanger where it will be pre-cooled using soft water. Additional hot soft water tank added to have a hot water buffer to supply the sterilizers and the boiler.

When designing the system, the following considerations have to be taken into account:

- The soft water tank pump is activated only when a sterilizer is on the initial cooling stage.
- The cooling tower and sterilizer feed water pumps have VFDs with pressure differential at the furthest point in the

- loop.
- The minimum flow valve controlled based on the pressure on the return pipe to the cooling tower to maintain a minimum flow requirement.
 - The high temperature protection valve is there to protect the cooling tower in case of a high temperature surge from the process. It should be controlled by the temperature after the heat recovery heat exchanger.
 - All hot pipes are insulated.
 - The steam heat exchanger in the feed water loop is to maintain stable feed water conditions to the autoclaves.
 - The ICV valve only opens during Initial Cooling.
 - The ECV valve only opens during extended cooling.
 - The amount of heat that can be used in the sterilizer's feed water is about 40% of the total recoverable energy. The rest of the energy can potentially be used for other applications like boiler feed water, ambient heating, and to preheat water for stills and WFI heat exchangers.
- [2] U.S. Department of Energy. (2012). Energy Efficiency and Renewable Energy: Advanced Manufacturing Office.
- [3] Fundamentals of Momentum, Heat, and Mass Transfer, Revised 6th Edition, James Welty, Gregory L. Rorrer, David G. Foster.
- [4] Consumer Affairs Sector - Ministry of Electricity and Water (Kuwait).
- [5] Ministry of oil (Kuwait).
- [6] Kuwait institute for scientific research.
- [7] International Energy Agency (IEA). (2022). Energy Efficiency 2022. IEA Publications.
- [8] ASHRAE. (2021). ASHRAE Handbook—Fundamentals. American Society of Heating, Refrigerating and Air-Conditioning Engineers
- [9] ISO. (2018). ISO 50001: Energy Management Systems-Requirements with Guidance for Use. International Organization for Standardization

The following table shows the estimated cost for implementing the project:

Table 3: Estimated Cost for Implementing the Project

| Item | Cost |
|-----------------------|-----------|
| Heat Exchanger | \$168,330 |
| Feed water tank - Hot | \$15,500 |
| Pumps | \$21,000 |
| Piping | \$52,000 |
| Other | \$31,000 |
| Total | \$287,830 |

The savings of the project depend on the uses of the hot soft water recovered in this system. There are 8,854MMBTU/year of energy savings in using the water for sterilizer's feed water, and 1,488MMBTU/year in using the water for boiler make-up. Total savings are estimated to be 10,342MMBTU of steam and 23,612kWh from the cooling towers for total cost savings of \$77.654/year (=23.612kd).

5. Conclusion

This study demonstrated that significant energy savings and operational improvements can be achieved in plastic processing plants through effective steam system management and boiler optimization strategies. The investigation identified three major improvement areas, including sterilizer startup control, optimization of boiler blowdown operation, and recovery of waste heat from sterilizer cooling processes. Implementation of these measures can reduce steam demand fluctuations, stabilize system pressure, improve boiler efficiency, and decrease fuel consumption and operating costs. The proposed heat recovery system also provides substantial opportunities for thermal energy reuse within the facility. Overall, the study confirms that systematic energy evaluation and process integration can improve both economic performance and operational reliability in industrial steam systems

References

- [1] Fundamentals of Heat and Mass Transfer SEVENTH EDITION.