AUTOCLAVE DEVICE EXERGY AND ENERGY ANALYSIS IN HOSPITAL STERILIZATION UNITS

by

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Original scientific paper
https://doi.org/10.2298/TSCI2204955S

One of the biggest problems in the world and in our country is energy. Energy use in Turkey is increasing gradually. As a result, an economic burden is created on the country with energy dependent on foreign sources. For this reason, energy should be used in the most efficient way to reduce energy costs and environmental impacts. It is one of the places where energy use is high in hospitals operating on a 24-hour basis. In this study, exergy and energy analysis of autoclave devices in the sterilization unit of Isparta Suleyman Demirel University Research and Application Hospital were made and the energy recovery potential was evaluated. As a result of the calculations, the average exergy loss of the autoclave was found to be 1.0376 kW, and as a result of the energy analysis, the average loss in the boiler was found to be 0.117655 kW. Similarly, the energy and exergy efficiency of the autoclave were calculated as 10% and 89.75%, respectively.

Key words*: exergy, energy, autoclave, efficiency, hospital*

Introduction

With the development of technology and the increase in population in the world, energy production and consumption are increasing rapidly day by day. Hospitals are one of the places with the highest energy consumption in Turkey. In hospitals, there are important expense items such as personnel, medication, medical device purchase and maintenance [1]. Another important expense in hospitals is energy. In studies conducted in Turkey, it has been determined that more than 10% of hospital expenses are fuel, electricity and water expenses. However, it differs on a hospital basis. [2, 3]. It is important for public or private hospitals, which work 24 hours a day, to use resources correctly and to ensure energy efficiency. One of the studies within the scope of energy economy is the issue of energy efficiency. By providing energy efficiency in hospitals, energy costs will be reduced.

In recent years, energy efficiency has been involved in the efficient use of resources. The energy efficiency law numbered 5627 was published in the Official Gazette No. 26510 on May 2, 2007 in order to prevent waste, relieve the economy and protect the environment by ensuring the efficient use of energy in our country [4]. Another important development in this area is the entry into force of the *Regulation on Increasing Efficiency in Energy Resources and the Use of Energy* numbered 28097, published on October 27, 2011, in order to regulate the procedures and principles of the energy efficiency law published in 2007 [5]. Finally, the National Energy Efficiency Action Plan was published in the Official Gazette on 02.01.2018 with the Decision of the High Planning Council dated 9/12/2017 and numbered 2017/50 [6, 7].

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With these decisions, it is understood that our country has been working very diligently in order to achieve energy efficiency targets in the short and medium term. Turkey is aware that the primary basis for improving energy security is to slow the rate of increase in consumption by increasing energy efficiency. To this end, the National Energy Efficiency Action Plan, covering the period 2017-2023, aims to reduce Turkey's primary energy consumption by 14% from usual business levels in various sectors, including buildings and services, power and heat [8].

The health sector in Turkey is growing steadily. According to the Statistical Yearbook of the Ministry of Health, approximately 720 million patients receive health services from the hospitals of the Ministry of Health every year [9]. Accordingly, applications to hospitals are increasing in Turkey. However, the physical capacities of hospitals, the technology used, the number of health manpower, and the number of medical procedures performed increase. On the other hand, the uninterrupted service of health institutions results in the continuous use of energy in order to meet the needs such as lighting, air conditioning, electricity consumption and heating at any time [10].

In the literature, some studies have been conducted on energy efficiency in the field of health. Some of those, Teke *et al.* [11] in this study, electricity saving possibilities in a university hospital were investigated. Pay-back periods for structural changes in HVAC, building insulation and lighting have been calculated. It has been demonstrated that 10% energy savings can be achieved with simple measures. It has been determined that there is a total energy saving potential of 20-40% by listing the measures that can be taken and the related components. In a study conducted by Beypazarli *et al.* [12], the energy efficiency of air conditioning systems in health institutions was emphasized. They concluded that 34% of energy savings can be achieved.

Figure 1. Sterilization photo

Material and method

In this study, exergy and energy analysis of autoclave devices in the sterilization unit of Isparta Suleyman Demirel University Research and Application Hospital were made and the energy recovery potential was evaluated. As can be seen in fig. 1, there are three separate autoclave devices used for sterilization.

Sterilization

Sterilization is the process of eliminating all microorganisms in the environment [13]. Confidence of sterilization in the manufacture and use of medical supplies is ensured by standard operating procedures. Inadequate sterilization of reusable medical supplies can cause infections [14]. Sterilization is an important step in controlling the death and cost increase caused by hospital infections. A large part of hospital expenditures is used for sterilization of reusable materials in the operating room [15]. Sterilization method varies according to the material to be sterilized. Main sterilization methods: sterilization with heat (sterilization with pressurized steam, sterilization with dry hot air), sterilization by filtration (filtration), sterilization by rays (irradiation), and chemical sterilization. Autoclave devices, which are the most widely used steam sterilization method. Because water vapor does not harm human health. Autoclave devices; It is used for sterilization in fields such as medicine, dentistry, veterinary medicine, food. [16, 17].

Autoclave

Autoclaves are devices that operate using the pressure steam sterilization method. The basic principle here is sterilization in saturated and pressurized water vapor above 100 °C. In this method, the high energy carried by the pressurized water vapor denatures the proteins of microorganisms through hydrolysis and creates an effect in a short time. In autoclave sterilization, it changes depending on the temperature, pressure, application time and humidity values. Autoclave pressures against different temperature values are given in tab. 1 [18].

Table 1. Autoclave temperature pressure relationship

Temperature [°C]	Pressure [kgcm^{-2}]
100	0.00
105	0.19
110	0.41
115	0.67
121	1.02
125	1.29
130	1.67
134	2.00

Temperature, pressure and application times sufficient to ensure sterilization in pressurized steam sterilization according to world standards. It is at least 3.5 minutes under 1.5 atmosphere pressure for 134 °C and at least 7 minutes under 1.5 atmosphere pressure for 121 °C. The basic principle is to ensure that every point of the material to be sterilized is in contact with saturated water vapor at a certain temperature for a sufficient time. Therefore, the packages should be placed loosely in the autoclave. In order to provide saturated steam, the time is started after reaching sufficient heat and pressure.

Structure of autoclaves. They are pressure resistant boilers that can be adjusted to a certain pressure and temperature. The parts of the autoclave are: Cauldron – there are different sizes. In small autoclaves, the boiler is single-walled, while in large ones, it is double-walled. Cover – it should be tightly closed to prevent air leakage. Thermostat – it keeps the temperature at a certain level. Electricity is used as a heat source. Air evacuation cock – it is a faucet that is kept open when the autoclave first starts to heat up and closed when saturated water vapor starts to come out, or it is a faucet where the autoclave air is evacuated by vacuum. Pressure regulating valve – it allows the steam to escape after a certain pressure and keeps the pressure constant. Manometer and thermometer – they are two indispensable parts in autoclaves, one for measuring pressure and the other for temperature [18].

Findings

Energy efficiency analyzes were carried out by making detailed measurements of the autoclave devices in the sterilization unit. The images of the autoclave front, back and side surfaces obtained as a result of the measurement made with the thermal camera are given in fig. 2. As a result of this measurement, the average temperature data related to the surface temperature of the pressurized steam boiler and the locations of the thermal losses were determined.

Exergy analysis of autoclave

Specific exergy or availability of a substance when it has specific enthalpy, h, and specific entropy, s, at temperature, T, and pressure, P:

$$Ex = \left(h - h_0\right) - T_0\left(s - s_0\right) \tag{1}$$

it is expressed by the equation [19].

Exergy analysis of the autoclave device in the sterilization unit was performed. It uses the steam energy at a certain pressure and temperature that comes ready in the autoclave. Some of this hot steam is discharged from the autoclave surface, and some of it is discharged through the

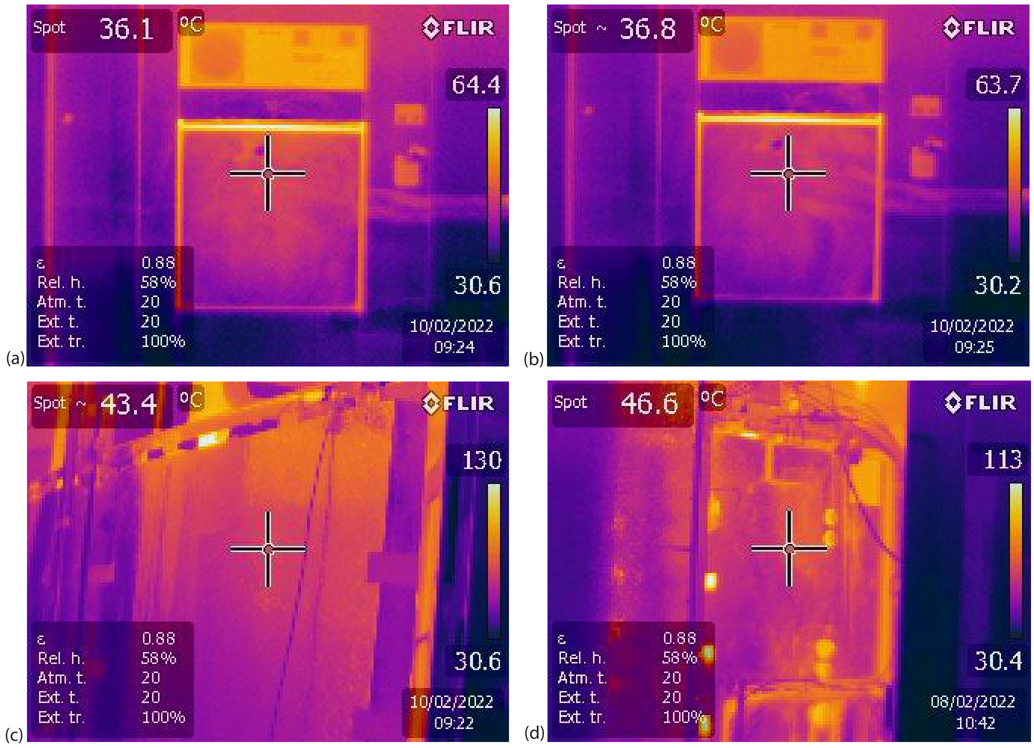

Figure 2. Thermal image of the autoclave; (a) front, (b) back, (c) left side, and (d) right side surface

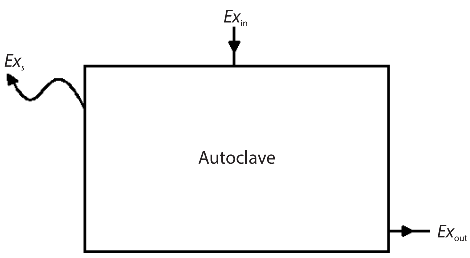

Figure 3. Autoclave exergy factors

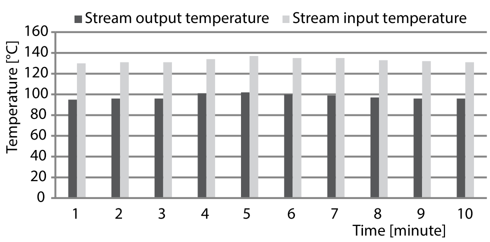

Figure 4. Autoclave steam inlet and outlet temperature values over time

steam discharge pipes. The size of the unusable heat is important for the efficiency of the autoclave. Considering these parameters, the exergy factors of the autoclave are shown in fig. 3.

Exergy of steam entering and leaving the autoclave

Steam inlet and outlet temperatures are important in the exergy calculations of the autoclave. In fig. 4, these change values at 2 minute intervals during the 20 minute operation of the autoclave are given. Autoclave inlet steam temperature varies between 130-137 °C, exit steam temperature varies between 95-102 °C.

In order for the autoclave to provide the internal heating value, there is a steam inlet from a central power plant system at 2.2 bar at 131 °C. This steam is then evacuated out of the autoclave. Buddha outputs at 2.2 bar at approximately 101 °C. The thermal images of the measured values are shown in fig. 5.

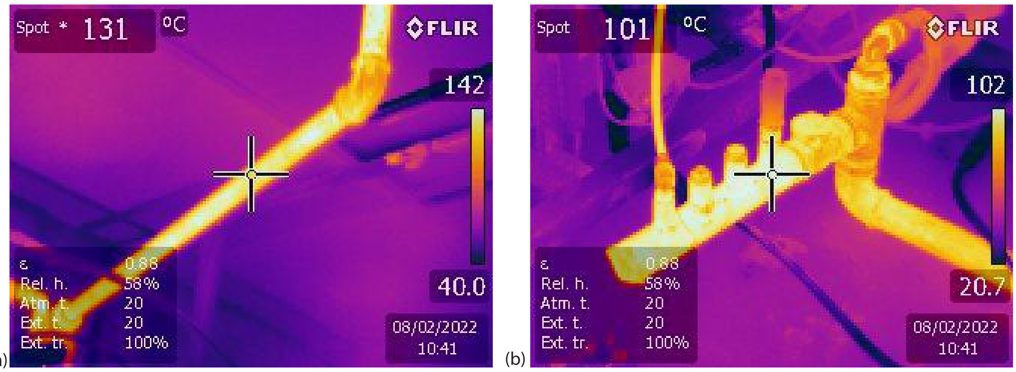

Figure 5. The thermal image of the autoclave steam; (a) inlet and (b) outlet

The exergy of the steam entering the autoclave and the exergy of the exiting steam are calculated, respectively:

$$Ex_{\text{sin}} = \dot{m}_{\text{steam}}\left[\left(h_{\text{in}} - h_0\right) - T_0\left(s_{\text{in}} - s_0\right)\right] \tag{2}$$

$$Ex_{\text{sout}} = \dot{m}_{\text{steam}}\left[\left(h_{\text{out}} - h_0\right) - T_0\left(s_{\text{out}} - s_0\right)\right] \tag{3}$$

The enthalpy, entropy and autoclave exergy changes obtained depending on the autoclave inlet and outlet temperatures as a result of the measurements are calculated with the help of eqs. (2) and (3) and given in tab. 2.

Table 2. Enthalpy, entropy and exergy values that change over time depending on the boiler inlet and outlet temperatures

Time [min]	T_{env} [°C]	Input				Output			
		T_{in} [°C]	h_{in} [kjkg^{-1}]	S_{in} [kJkg^{-1}K^{-1}]	Ex_{in} [kW]	T_{out} [°C]	h_{out} [kJkg^{-1}]	s_{out} [kJkg^{-1}K^{-1}]	Ex_{out} [kW]
t_1	302.7	403.2	2725	7.132	1.146	368.2	398.4	1.251	0.05229
t_2	302.7	404.2	2728	7.137	1.147	369.2	402.6	1.262	0.05379
t_3	302.7	404.2	2728	7.137	1.147	369.2	402.6	1.262	0.05379
t_4	302.7	407.2	2734	7.153	1.150	374.2	423.7	1.319	0.06162
t_5	302.7	410.2	2740	7.169	1.153	375.2	427.9	1.330	0.06324
t_6	302.7	408.2	2736	7.158	1.151	373.2	419.5	1.308	0.06001
t_7	302.7	408.2	2736	7.158	1.151	373.2	419.5	1.308	1.06001
t_8	302.7	406.2	2732	7.148	1.149	370.2	406.8	1.274	0.05532
t_9	302.7	405.2	2730	7.143	1.148	369.2	402.6	1.262	0.05379
t_{10}	302.7	404.2	3728	7.137	1.147	369.2	402.6	1.262	0.05379

Losses by heat transfer from the autoclave surface

There is a heat transfer from the autoclave surface to the environment. This transition is called the loss from the boiler surface. It can be calculated:

$$Ex_{\text{surface}} = Q_s\left(1 - \frac{T_0}{T_s}\right) \tag{4}$$

$$Q_s = A_s a_s \left(T_s - T_0\right) \tag{5}$$

Autoclave side surfaces, back and front surface temperatures were measured with a thermal camera. The measurement results are given in tab. 3 in the table of autoclave dimensions and average temperature values.

Table 3. Autoclave dimensions and average temperature values

Surface	*x* [m]	*y* [m]	Area [m^2]	Average surface temperature [°C]
Front	0.65	0.65	0.4225	36.1
Back	0.65	0.65	0.4225	36.8
Left side	0.85	0.65	0.5525	43.4
Right side	0.85	0.65	0.5525	46.6

The surface heat losses calculated according to the measured values are given in tab. 4.

Table 4. Calculated surface heat losses

Surface	Area [m^2]	Ambient surface temperature [K]	Average ambient temperature [K]	Q_S	Exsurface [kW]
Front	0.4225	310.0	302.7	3.08425	0.07262
Back	0.4225	309.3	302.7	2.78850	0.05950
Left side	0.5525	316.6	302.7	7.67975	0.33717
Right side	0.5525	319.8	302.7	9.44775	0.50517
				Total	0,97446

Discussion and conclusion

In this study, energy efficiency measurements were made for the autoclave device in Isparta Suleyman Demirel University Medical Faculty Sterilization Unit. Exergy losses due to autoclave surface area and steam inlet and outlet were calculated. The total exergy loss of the autoclave is equal to the difference between the inlet steam exergy and the output steam exergy plus the sum of the exergy of the surface losses. As a result of the calculations, the total exergy loss of the autoclave depending on time is shown in fig. 6. It has been stated that this efficiency value should be increased, as the exergy efficiency of the autoclave is 89.75% and the average exergy loss is 0.117655 kW. In addition, the total heat losses of the autoclave were calculated to be 10%.

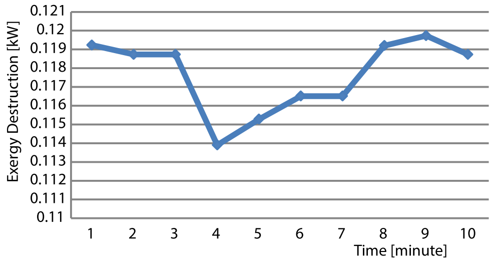

Figure 6. Total exergy loss of the time-dependent autoclave

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Paper submitted: May 13, 2021
Paper revised: October 11, 2021
Paper accepted: April 23, 2022