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IMPROVING ECO-EFFICIENCY BY AUDITING STEAM AND CONDENSATE SYSTEMS

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Several assessments of steam and condensate systems have been carried out (in textile plants, an animal food production plant, in processing of waste from a slaughterhouse, in the boiler house). The methodology of the assessment includes flowsheet, mass and energy balances of the process and boiler house, identifying all steam consumers, the flowsheet of steam and condensate systems, studying pressure and temperature levels, determining the database of pressure reducing valves and steam traps, producing rational steam consumption and effective steam production options, and making technical, economic and environmental assessments. Only the most beneficial options should be proposed and implemented.

The analyses show that several options can improve the eco-efficiency of a plant. Efficiency of boilers can be improved by heat recovery from blowdown, from flue gas and deaerating gasses, control of the combustion process, etc. The steam should be efficiently consumed, all steam traps should be correctly selected and installed in the process. The staff should regularly check the operating of the steam and condensate armatures, seek for leaks, etc.

The results show that it is possible to reduce the production of flue gas emissions by more than 10 %, wastewater by 5 %, fuel by 8 % and waste heat up to 20 %. Payback periods of the proposed options reach up to 1.1 years.

Keywords: cleaner production; eco-efficiency; steam and condensate systems

Introduction

The concept of eco-efficiency was first introduced in 1992 by the Business Council for Sustainable Development (BCSD) in its landmark report, Changing Course. In November 1993 it was finally defined at the first Antwerp Workshop on Eco-efficiency. It involves the delivery of competitively priced goods and services that satisfy human needs and bring quality of life, while progressively reducing ecological impacts and resource intensity throughout the life cycle, to a level at least in line with the earth's estimated carrying capacity [1]. Seven success factors for eco-efficiency have been identified:

- to reduce the material intensity of goods and services;
- to reduce the energy intensity of goods and services;
- to reduce toxic dispersion;
- to enhance material recyclability;
- to maximise sustainable use of renewable sources;
- to reduce material durability;
- to increase the service intensity of goods and services.

A similar concept, which has been promoted elsewhere, especially through the United Nations Environmental Programme (UNEP), is Cleaner Production. Eco-efficiency embraces cleaner production concepts such as efficient use of raw materials, pollution prevention, source reduction, waste minimisation and internal recycling and reuse. But it emphasises value creation for businesses and the society by improving competitiveness of the companies, their products and services. Cleaner production is a continuous application of an integrated environmental strategy applied to processes, products, and services to increase eco-efficiency and reduce risks for humans and the environment. There are numerous cleaner production and eco-efficiency projects, which are successfully being introduced in industry. A common feature of all of them is that an integral approach was used. The latter consists of several steps, which should be gradually adopted in order to find large waste producers and energy consumers. Part of this approach could be the analysis of the steam generation,

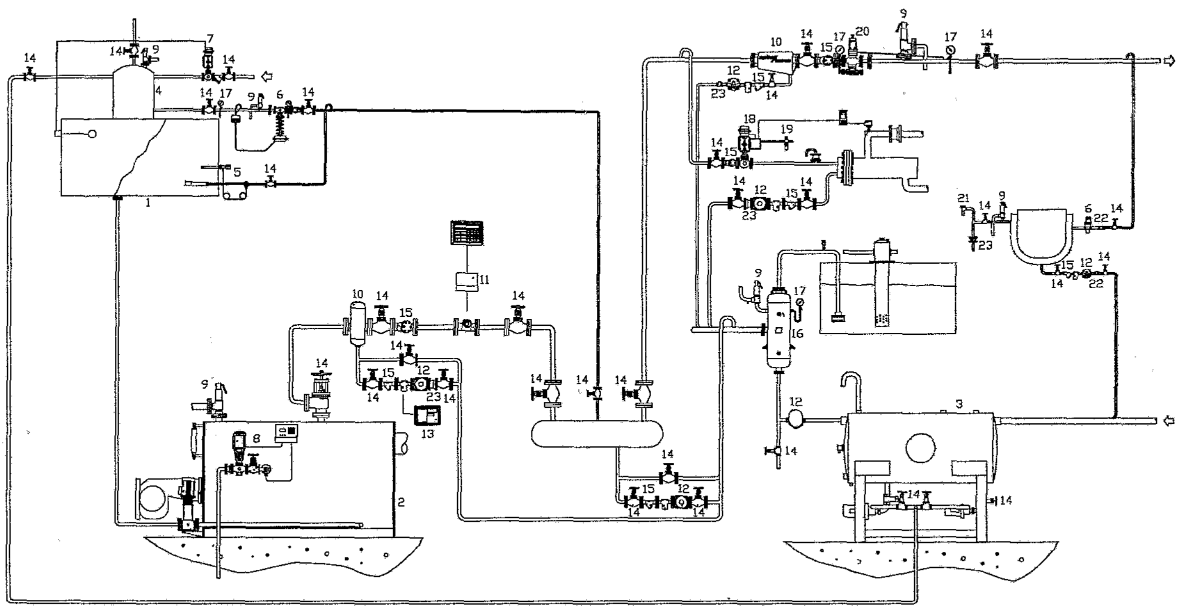

Fig.1 A typical steam and condensate system (1 Feedtank; 2 Steam generator; 3 Condensate receiver with electric powered pumps; 4 Deaerator; 5 Steam injection and temperature control system; 6 Direct acting pressure reduction valves; 7 Level control; 8 Auto TDS system; 9 Safety valves; 10 Steam separator; 11 Steam meter; 12 Steam traps; 13 Steam trap monitors; 14 Stop valves; 15 Separators; 16 Flash vessel; 17 Pressure gauges; 18 Pneumatic pressure control system; 19 Compressed air regulator; 20 Pilot actuated pressure reducing valve; 21 Air vents; 22 Check valves)

distribution, utilisation, and condensate recovery [2]. Another well-known approach is energy auditing. It consists of a detailed examination of how the facility uses energy, how much the facility pays for the energy, and finally a recommended program for changes in the operating practice or in energy-consuming equipment that will cost-effectively save money for energy [3]. All kinds of energy and energy carriers are included, e.g. electricity, fuels, heat carriers (hot water, steam or other heat transfer fluids), cooling agents, and compressed air. Steam and condensate system analysis should be part of the auditing of the complete company's utility and energy system.

Steam and Condensate System

Steam has been used since the 18th century to supply power and heat to industrial and commercial organisations. It is one of the most abundant, least expensive, and most effective heat-transfer medium obtainable. Steam can transfer large amounts of energy compared to water systems, which can be transferred without additional power at a constant temperature. It can be accurately determined by controlling the steam pressure. It is clean, non-toxic, non-flammable and comes from water, which is an abundant resource.

Fig.1 shows a typical steam and condensate system. It consists of a steam boiler, steam distribution system, steam users, and a condensate recovery system. The boiler installed in a boiler house is supplied by feed water, which is a mixture of make-up water, and the condensate returned from the steam users. Feed water requires a proper treatment to prevent boiler corrosion and to reduce water carry-over due to foaming. It has to be physically and/or chemically treated to reduce dissolved solids, i.e. primarily hardness; dissolved gasses, i.e. primarily oxygen and carbon dioxide must be removed by deaeration.

The boiler produces steam at the highest pressure and temperature required by the process. The steam is distributed through large steam mains to the process and then through transfer lines to each piece of equipment. The steam distribution system has to be properly designed, therefore steam pipes should be correctly sized for flow according to pressure drop or steam velocity, a separator should be installed for removing water droplets and condensate in order to improve steam dryness and prevent water hammer. Steam lines should slope down so that condensate can drain by gravity, and at the end of the steam mains steam traps and air vents should be installed. Steam should be taken from the top of the steam main because the driest steam is there. If some processes require lower steam temperature, steam is throttled to lower pressure through a pressure-reducing valve.

Steam is used in different kinds of equipment for heating purpose [4]. The type of equipment used depends on the type of processes, but usually there are several kinds of heaters, reactors, ovens, sterilisers, retorts, digesters, vulcanisers, evaporators, calandrias, reboilers, dryers, ironers, tumblers etc. The condensate produced in the heating spaces has to be correctly removed in order to prevent drainage and corrosion so that efficient heat transfer is maintained [5]. It is discharged into the condensate system through steam traps (thermostatic, mechanical or thermodynamic). Traps operate at different pressures, which is why check valves should be installed to prevent condensate backflow. Condensate mains should be designed for two-phase flows and should slope downhill to the receiver. The flash steam is the best way of decreasing the condensate pressure and preventing backpressure in the condensate system. The use of low pressure steam can substantially improve the efficiency of the steam and condensate system. The condensate, collected in the receiver, has to be pumped to a higher point - usually to the boiler feed tank. There are two kinds of pumps to be used: the electric-driven centrifugal pump or the pressure powered automatic pump. It sometimes is useful to install condensate contamination detectors to prevent the contaminated condensate from being pumped into the boiler [6]. Ref.[3] represents a checklist of energy conservation opportunities in steam and condensate system:

1. Review the operation of long steam lines to remote single-service application. Relocate remote equipment.
2. Review the operation of steam systems used only for occasional services. Use temperature controlled valves to assure system to be used when needed.
3. Implement regular steam leak survey and repair programs.
4. Establish a regular steam-use monitoring program to track the progress in the reduction of steam consumption.
5. Consider the revision of plant-wide steam balance in multipressure systems to eliminate venting of low-pressure steam.
6. Check the actual steam usage of the equipment against the theoretical or design requirements to find disparities, determine the cause and correct it.
7. Review the pressure-level requirements of the steam-driven mechanical equipment to evaluate feasibility of using lower pressure levels.
8. Review the pressure requirements in the process and reduce the temperatures to the minimum acceptable level.
9. Evaluate the production scheduling of batch operations and revise it if possible to minimise start-ups and shutdowns.
10. Implement a regular steam trap survey and maintenance program.
11. Check the sizing of all steam traps to make sure they are adequately rated for proper condensate drainage.
12. Review the types of traps in various services to assure that the most efficient trap is used for each application.
13. Survey the condensate sources presently being discharged to waste drains for feasibility condensate recovery.
14. Consider the opportunities for flash steam utilisation in low-temperature processes.
15. Consider pressuring atmospheric condensate return systems to minimise flash losses.
16. Review the mechanical drive standby turbines presently left in the idling mode and consider the feasibility of shutting down standby turbines.
17. Implement a steam turbine performance testing program and clean the turbine on a regular basis to maximise efficiency.
18. Evaluate the potential for cogeneration in multipressure steam systems presently using large pressure - reducing valves.
19. Survey the insulation of the equipment and piping to locate areas of insulation deterioration. Maintain insulation on a regular basis.
20. Insulate all uninsulated lines, fittings, valves, flanges and small lines.

Auditing Steam and Condensate Systems

In the last two years several steam and condensate systems have been analysed in animal food production, meat processing and textile industry. In the following paragraphs, some interesting results will be described.

Animal Food Production

Steam was used primarily for the sterilising and keeping of proper water content in the pellets. Therefore the steam was mixed with the product which made the returning of the condensate impossible. Since the older steam boiler was damaged the company invested in a new one together with boiler feed water treatment. Instead of deaerating feed water they used chemicals for oxygen removal. Because dissolved gases were not efficiently removed from the feed water, corrosion of the heating coil occurred which was why it had to be changed every two years.

The consumption of heating oil was 66 t y^{-1} and of process steam 900 t y^{-1}. 31 000 t of animal feed pellets were produced, 1 380 t y^{-1} of flue gas, 60 t y^{-1} of waste water from blowdown, 28 kW of waste heat, while 204 t y^{-1} of condensate were lost with 45 kW heat content released into the environment. The analysis of the whole steam and condensate system showed that the production and distribution of the steam were inefficient and formed condensate in the distribution system which due to heat losses was not returned into the steam boiler. Several options were proposed to improve efficiency of the system and to cut the costs:

1. Deaeration of the feed water. The investment demanded a new feedtank, a deaerator and armatures (stop valves, pressure reduction valve, a self acting temperature control system and feedwater pump);
2. Condensate recovery. Due to heat losses the formed condensate should be returned into the feedtank. The investment demanded pipes and insulation.
3. Replacing of inefficient and broken steam traps.

From *Table 1* it is evident that the payback period was approximately 16 months, while *Table 2* shows the reduction of waste water and waste heat, flue gas emissions, savings of fuel and chemicals.

Table 1 Investment and savings of the suggested rational steam production and consumption in animal feed production

Alternative	Investment (USD)	Savings (USD y^{-1})	Payback period (year)
1	14 300	11 500	1.2
2	1 800	600	3.0
3	500	300	1.7
Total	16 600	12 400	1.3

Table 2 Reduction of effluents, fuels and chemicals

	Reduction	Fraction (%)
Chemicals (L y^{-1})	130	100
Water (m^3 y^{-1})	204	23
Fuel (kg y^{-1})	3 200	5
Flue gas emissions (t y^{-1})	67	5
Waste heat (kW)	9	4

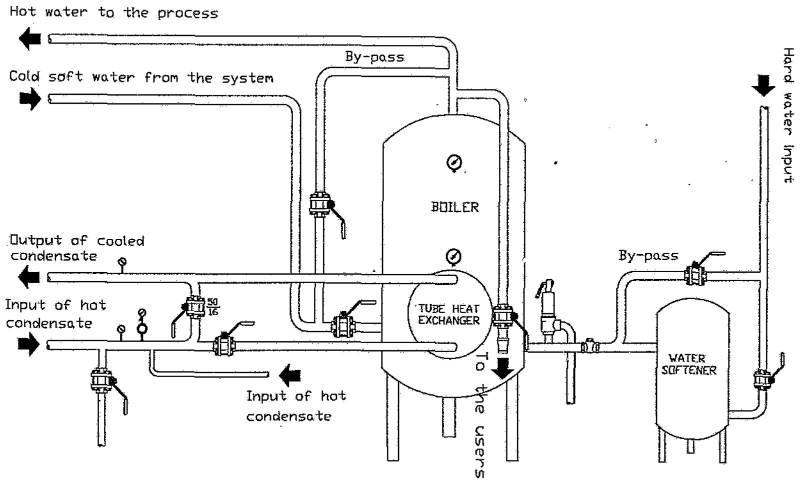

Fig.2 Flash steam recovery

Retrofitting of Steam and Condensate System in the Plant where the Waste from Broilers Slaughterhouse is Treated

Waste meat, blood and plumage from the broiler slaughterhouse were processed into useful products (fat, bone meal and plumage meal) and currently used in the production of animal feed. Waste is decomposed into five reactors heated by steam. Two air heaters, two fat tanks and a filter press are also installed. The annual production of bone meal reached 1 770 t, of plumage meal 1 280 t and of fat 1 250 t. Steam consumption amounted up to 15 000 t y^{-1}.

The audit of the steam and condensate system involved a flowsheet, a mass and energy balance, a datasheet of all steam traps, reducing, safety, regulating and stop valves, separators and other armatures, proposed alternatives for rational steam distribution, consumption and condensate recovery.

Three ways of improving the steam and condensate system were proposed:

1. Eliminating of steam and condensate leaks, maintaining insulation, retrofitting steam and condensate pipes, replacing inefficient and broken stop and reducing valves.
2. Replacing of inefficient and broken steam traps. 29 steam traps were monitored, all types of traps were reviewed and the most efficient traps for every application installed. 19 steam traps were found inefficient or broken.
3. Flash steam recovery. Flash steam produced at passing through steam traps at substantial pressure drop is used for heating process and cleaning water (*Fig.2*).

After the implementation of the proposed measures, steam consumption was reduced by 5 % and condensate saved by 8 %. Savings reached 15 000 USD y^{-1} at investment costs of 16 000 USD. The payback period was approximately 1.1 year.

Designing of an Optimal Condensate System

The meat processing company installed new equipment for treating sausages. The production of sausages demands sterilising, cooking, washing and treating in smoking chambers. High pressure steam was needed for heating the air in the chambers and low pressure steam for cooking. The equipment producer designed a steam system and proposed the collecting of condensate in an aerated tank and the pumping of it into the boiler house by an electric-driven pump.

After studying the possibilities for an optimal condensate recovery system, several options were suggested. Three of them are: the drainage of high pressure condensate under pressure into a receiver, the collecting of condensate into an aerated receiver and the pumping of it by an electric-driven pump, and the flash steam recovery with pumping low pressure condensate into the condensate receiver by a pressure - powered pump.

Technical and economical assessments showed that the last option was the best of the three. Flash steam produced from high pressure condensate was used for cooking sausages, while low pressure condensate was collected in a receiver and pumped by a steam powered pump into the condensate tank (*Fig.3*).

Table 3 Savings, investment and operating costs of the proposed two options

	Option 2	Option 3
Investment (USD)	17 500	12 500
Operating costs (USD y^{-1})	300	3 000
Losses (USD y^{-1})	1 200	-
Savings (USD y^{-1})	-	5 000
Payback period (year)	-	6.2

Table 5 Reduction of flue gas emission, waste water and waste heat

	Reduction	Mass fraction of total (%)
Flue gas (t y^{-1})	1 483	16
Waste water (m^3 y^{-1})	43	16
Waste heat (MW y^{-1})	91	16

Table 4 Investment, savings and payback periods

Alternative	Investment costs (USD)	Savings (USD y^{-1})	Payback period (year)
1	7 000	17 000	0.4
2	19 000	20 000	0.9
Total	26 000	37 000	0.7

Table 6 Dependence of payback period and specific savings

Process	Payback period (year)	Savings (USD t^{-1})
Pellets production	1.3	0.4
Waste treatment	1.0	3.5
Threads and bands production	0.7	117.1

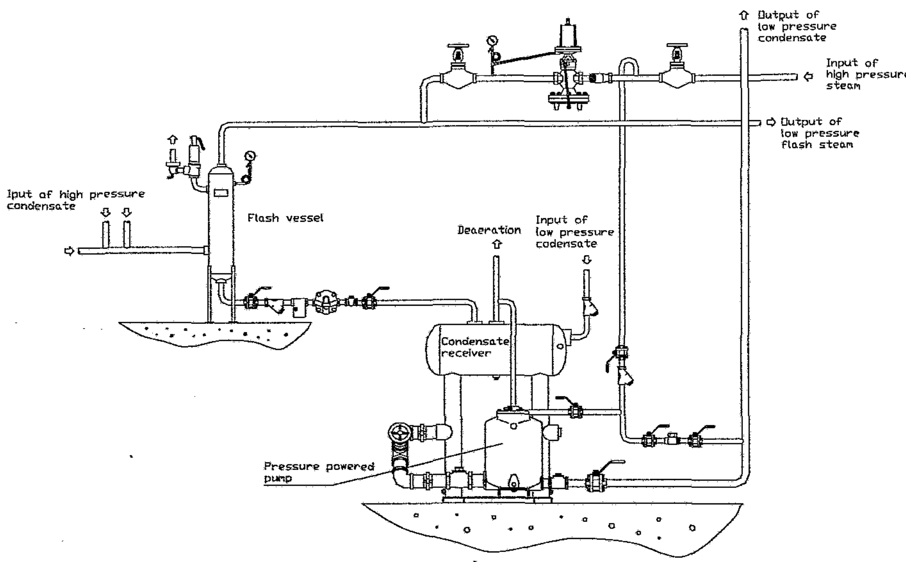

Fig.3 Flash steam recovery, collecting and pumping of low pressure condensate

Table 3 shows the savings, the investment and operating costs of the second and third option, which were technically feasible. The third option has lower investment and higher operating costs (steam for driving the pump), and substantial savings of condensate and steam compared with the second option.

Integration of a Steam Boiler into the Threads and Yarn Production Process

A thread and yarn producing company was being supplied with steam and hot water for heating by a nearby company. As the costs of steam and hot water kept rising they decided to invest in their own boilerhouse. The external designer proposed a boilerhouse with two steam boilers of 4.92 MW.

Together with the company experts we carried out an assessment of the production, distribution, utilisation of steam and condensate recovery in order to decrease investment costs. In the first phase of research a flowsheet was produced, mass and energy balances were carried out. Some options for rational energy consumption were proposed in the second phase.

Renovation of the steam and condensate system. It included steam leaks prevention, replacing of inefficient pressure reduction valves and broken steam traps.

Recycling of cooling water and heat recovery from waste water. Warm water produced at the temperature of over 60 °C could be reused for the preparation of process solutions and for warm rinsing of threads. The investment demanded a warm water tank, pipes, valves and pumps.

Investment, savings of steam, water and payback periods are presented in *Table 4*. The total savings amount to 37 000 USD y^{-1}, the payback period is less than 9 months. Based on the results of mass and energy balance and of the proposed options, the company invested in one steam boiler with 1,97 MW instead in two with 4,92 MW. The free capacity of this boiler was further assessed and the possibilities for heating production buildings by hot water investigated. It was concluded that the capacity of the installed steam boiler satisfied the demands for the production process and heating of buildings. At the annual steam consumption of 6 500 t, 1 070 t were saved (which is approximately 16 %). Proposing a minimum steam capacity resulted in an additional 45 % reduction of depreciation costs (218

000 USD). The reduction of flue gas emissions, waste water and heat losses are presented in *Table 5*.

After installing the steam boilerhouse, additional possibilities of fuel savings were investigated. Waste heat recovery from flue gas and deaerating waste flow from the feedtank and by flash of a boiler blowdown were proposed. It was concluded that the proposed options could lead to an 0.8 % improvement of the boiler efficiency and the boilerhouse by 4 %. The payback period of the proposed options was 4 years. It should be possible to decrease fuel consumption by 8 %, boiler water consumption by 2.5 % and flue gas emissions by 10 %.

Conclusions

Auditing of the steam and condensate system is a useful procedure for saving fuel, steam, water and for reducing effluents into the environment and therefore for improving the eco-efficiency of the company especially where the reduction of the energy intensity of goods and services is concerned. Savings depend on the size, and the conditions of steam and condensate system as well as on efficiency of using steam in the process. In *Table 6* payback periods of the proposed options are presented and specific savings per product are shown.

Besides the above mentioned energy conservation opportunities there are also other energy conservation possibilities for improving eco-efficiency in steam and condensate systems:

- Design of an optimal steam and condensate system after the steam demand in the process is established.
- Considering the possibility of pumping low pressure condensate with a pressure-powered pump instead an electric-driven one.
- Considering the possibility for heat recovery from flue gas, deaerating waste flow, boiler and bottom blowdown.
- Installing a total dissolved solids (TDS) control system for boiler blowdown and a time programmed bottom blowdown system.
- Considering the possibility of waste heat recovery from process waste streams in order to decrease steam usage for heating.

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