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OPTIMUM DISTRIBUTION OF LIVE STEAM PRODUCTION BETWEEN THREE UNITS OF POWER PLANT LJUBLJANA

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ABSTRACT
Power plant Ljubljana produces heat and power for Ljubljana, the capital of Slovenia. District heating system fed by Power Plant Ljubljana covers approximately 35 % of Ljubljana heat consumption. Maximum heat output is 340 MW. Units 1 and 2 were put in operation in 1967. Unit three operates since 1985. Maximum capacity of boilers 1 and 2 is 180 t/h each and of boiler 3 270 t/h of superheated steam at 95 bar and 530 °C. All three steam boilers are fired with coal. Due to different thermal efficiencies of boilers it is important to distribute live-steam production between the boilers in different periods of the year to minimize the specific heat consumption. The method for achieving this is presented in the paper.
Keywords: efficiency, coal-fired boiler, optimization

1. INTRODUCTION
It is very important for every power plant operator to continuously monitor the efficiency of operation. Every major modification of the plant can shift optimal operating regime and plant operators should find the way to adapt to new situations even before the modifications are made using what-if studies as for example **Error! Reference source not found.**.
Power Plant Ljubljana is a combined heat and power (CHP) plant. According to criteria stated in **Error! Reference source not found.** Power Plant Ljubljana demonstrates high-efficiency cogeneration. It consists of three units. Units 1 and 2 were put in operation in 1967. Unit 3 operates since 1985. Maximum capacity of boilers 1 and 2 is 180 t/h each and of boiler 3 270 t/h of superheated steam at 95 bar and 530 °C. Maximum heat output is 340 MW and maximum power output is 124 MW. All three steam boilers are fired with coal. Besides that boiler 3 has a grate for wood chips co-firing installed. Due to different thermal efficiencies of boilers live-steam production needs to be properly distributed among the boilers to minimize the specific heat consumption. This paper describes the method and results of the optimization of the distribution of live-steam production.

2. YEARLY SCHEME OF OPERATION
Table 1 shows yearly scheme of operation of units. The scheme is tuned to synchronize actual heat demand and heat production along with maximization of primary energy savings. There are mainly three different periods throughout the year with respect to ambient temperature: cold period (November till March), hot period (May till September) and warm/cool period (April and October).

Regarding the distribution of steam production among the three boilers savings are achievable only when more than one boiler is in operation.

Table 1. Yearly scheme of units operation

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Unit 1												
Unit 2												
Unit 3												

During periods with two boilers it is important that optimal boiler combination is selected and that steam production is optimally distributed among them. During period with three boilers only distribution of steam production is relevant. During hot period with only one boiler more factors than just boiler's specific heat consumption are important for boiler selection: maintenance of boilers and steam turbines, wood-chips cofiring, price of electricity…

3. BOILER EFFICIENCIES

Boiler efficiencies were measured during performance tests that are periodically performed in accordance with [**Error! Reference source not found.**] by Faculty of Mechanical Engineering of Ljubljana. Due to smaller size and older design boilers 1 and 2 have lower efficiency than boiler 3 (*Figure 1*). Boiler 3 also has an additional district-water heater placed in the flue gas duct after the induced draft fans where flue gas is cooled to 110 °C before entering the stack. Thermal efficiency of the boiler is reduced during wood-chips co-firing due to higher moisture content in wood-chips than in coal. This effect is illustrated by two efficiency curves representing operation without and with maximum wood-chips cofiring.

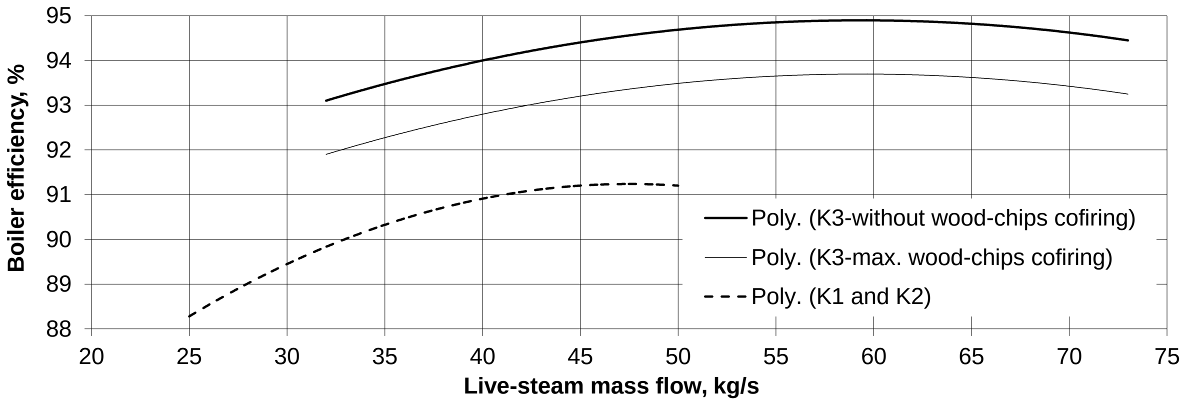

Figure 1. Measured boiler efficiencies

4. SPECIFIC HEAT CONSUMPTION

The goal of optimization is twofold:

- determination of optimal combination of boilers,
- determination of optimal distribution of total live-steam mass flow among the operating boilers.

Figure 2 shows specific heat consumption achievable at various total live-steam mass flows using different boiler combinations. Bold gray line highlights minimal achievable specific heat consumption.

Example: at 90 kg/s total mass flow two or three boilers can be in operation. Wood-chips co-firing is at its full load. Six different operating points are possible:

1. optimal boiler combination and optimal mass-flow distribution: boilers 1 (36,7 kg/s) and 3 (53,3 kg/s) are in operation (large black dot)
2. optimal boiler combination and not-optimal mass-flow distribution: boilers 1 (25 kg/s) and 3 (65 kg/s) are in operation (small black dot)

3. not-optimal boiler combination and optimal mass-flow distribution: boilers 1 (45 kg/s) and 2 (45 kg/s) are in operation (large gray dot)
4. not-optimal boiler combination and not-optimal mass-flow distribution: boilers 1 (40 kg/s) and 2 (50 kg/s) are in operation (small gray dot)
5. not-optimal boiler combination and optimal mass-flow distribution: boilers 1 (25 kg/s), 2 (25 kg/s) and 3 (40 kg/s) are in operation (large white dot)
6. not-optimal boiler combination and not-optimal mass-flow distribution: boilers 1 (30 kg/s), 2 (30 kg/s) and 3 (30 kg/s) are in operation (small white dot)

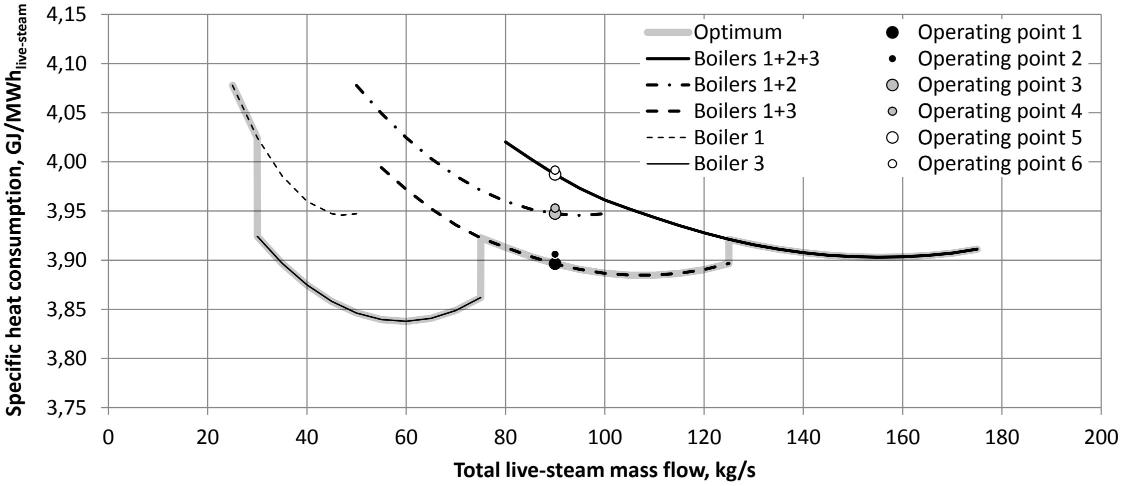

Figure 2. Achievable specific heat consumption

The above example shows that it is very important to choose optimal boiler combination. Distribution of live steam production among operating boilers is less important but still deserves consideration.

5. ACHIEAVABLE SAVINGS

In this chapter an estimation of savings for 2013 is done by comparing real and optimal distribution of steam production. During 2013 on-line optimization was not operational yet. Real distribution was obtained from archived power plant data while optimal distribution was calculated using the optimizer. Achievable savings represent the difference between actual and optimal heat consumption.

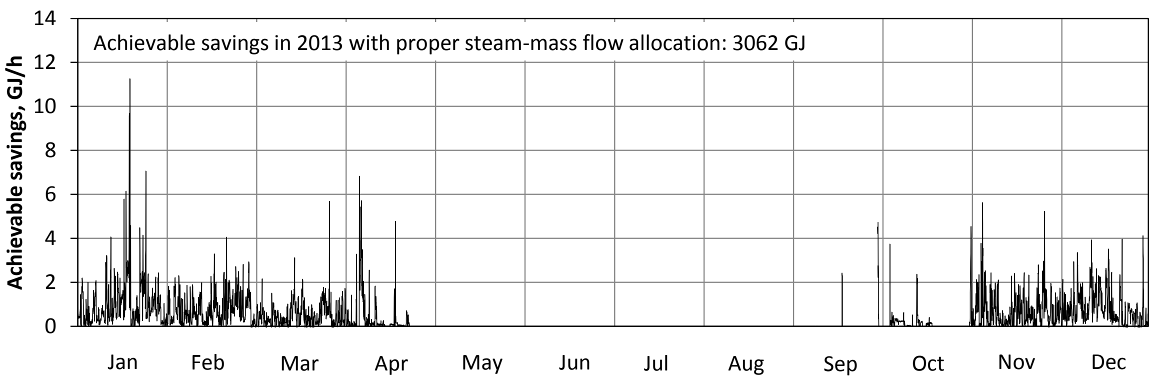

Figure 3. Achievable savings: optimal steam mass flow distribution & actual boiler combination

Figure 3 shows savings achievable by optimal distribution of steam production among operating boilers compared to actual distribution for every hour of the year 2013 (“A-savings”). Savings are feasible only from October to April i.e. in periods when more than one boiler is in operation. Savings add up to approximately 3000 GJ in year 2013. These savings are relatively small because of spontaneous optimization done by units’ operators.

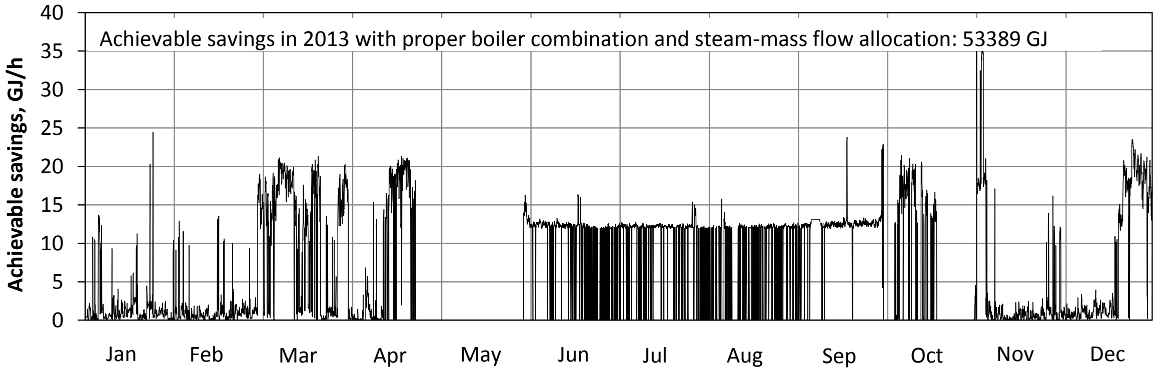

Figure 4. Achievable savings: optimal steam mass flow distribution & optimal boiler combination

Figure 4 shows savings achievable by optimal distribution of steam production and optimal boiler combination compared to actual distribution and actual boiler combination for every hour of the year 2013 ("B-savings"). "B-savings" (53389 GJ) are considerably bigger than "A-savings" (3062 GJ). During spring and autumn frequently boiler combination is not-optimal because heat demand fluctuates just around the level where optimal combination of boilers shifts from two to three or from one to two operating boilers. Since every stoppage and start of steam boiler causes additional costs not to mention additional stress to the equipment it is not reasonable to switch boilers on and off too frequently. Due to planned major maintenance stoppage of boiler 3 boiler 1 was in operation during summer although boiler 3 enables lower specific consumption of heat. It is therefore obvious that only a portion of theoretically achievable savings can be realized in practice. Nevertheless it is very important to know the optimal regime of operation and adopt it as soon as circumstances allow

6. CONCLUSION

Optimization presented in this paper is one of many optimizations that can be done in thermal power plants. Any optimization that can be processed without excessive costs is a must because it contributes to more efficient production of useful energy and thus lowers the emissions of harmful substances to the environment.

7. REFERENCES

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