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ENERGY EFFICIENCY OF STEAM PIPELINE SYSTEM

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Abstract: *This paper presents some measures for energy efficiency improvement in a steam pipeline which was built 54 years ago, and has been transporting steam needed for kraft paper and packaging manufacturing process. During the late 80's the pipeline was repaired and very high efficiency has been achieved. At the moment, only one part of the manufacturing process is in use and steam pipeline insulation is in very bad state, due to the lack of maintanance. Energy efficiency of steam pipeline is approximately 35 %, hence energy and money loses are tremendous. This work shows that some technical measures could improve energy efficiency up to 94,6 % in a profitable way.*
Key words: *energy efficiency, steam, heat losses*

1. INTRODUCTION

Many industrial facilities in Bosnia and Hercegovina have been built regarding to very high standards. Facility, which is a subject of consideration, has started to work 54 year ago. It has been used for kraft paper and packaging manufacturing process. By the beginning of the war in Bosnia, it was the largest producer of kraft paper and packaging in the Balkans and among the leaders in Europe. During the 90's it has been out of order for a while, afterward some segments of production have been started. At the moment, the factory is working with partial capacity. In this paper, the energy efficiency of one part of facility, a steam pipeline is considered. It was repaired 21 years ago and served as a steam supplier for two kraft paper machines. Reparation included an evaluation of steam capacity of existing pipe and calculation for the best suitable insulation which resulted in very high energy efficiency coefficient. At the moment, need for the steam flow is reduced and steam pipeline insulation is in very bad state due to the lack of maintenance. As a result, energy efficiency is very poor and reparation is necessary. In this paper the procedure for energy efficiency for steam pipeline is presented. Energy efficiency for the actual state of the pipeline is calculated and some measures for it's improvement are presented. Also, new and improved energy efficiency is calculated and evaluation of the money savings is presented.

2. GENERAL INFORMATION

Steam pipeline starts from steam collector, carrying steam with pressure 11,7 bar and temperature 340 °C. Afterward, it is brought outside and exposed to external conditions. Pipe length is 931 m, eqvivalent length is 69 m which makes total pipe length of L=1000 m. Steam pipe is made from steel, with inner diameter d_{in}=125 mm and wall thickness δ=4 mm. Insulation thickness is 100 mm. Inspection of the actuall state determent that pipe insulation need reparation. It is estimated that approximately 200 m of pipe does not have insulation at all, 400 m of pipe is covered with insulation which is exposed to raing and moisture, and 400 m of insulation is well preserved. Thermal measurements, shown on Figure 1., reveales that surface temperature of the uninsulated steam pipe is 187 °C,

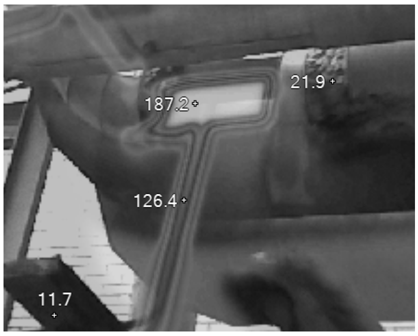

Fig. 1.Thermal and acctual image of the steam pipeline and steam trap

and it is a temperature of the saturation for the pressure of 11 bar. This shows that condensation takes place in these parts and heat loses from the pipe toward to the surrounding are tremendous.
In addition, steam traps installed in a system do not have capacity to remove all the condensate which appears in a pipe. Steam is delivered to the kraft paper machine, which consumes steam with minimal pressure and temperature 10,5 bar and 190 °C, respectively. There is no direct contact of steam with any fouling agents so condensate is pure and does not require any chemical treatman. Codensate is collected in a high pressure wessel, aftetward into a low pressure wessel, where a recuperation takes place. Energy, taken from the flash steam, is using to heat a water for the facility heating, which is highly benefitial. Condensate returnes in a process afterward.

3. CALCULATION PROCEDURE

While calculating the energy efficiency of a system, an overal efficiency of complete system could be calculated or only parts of the system could be considered. In this paper, steam production process is not a subject of consideration, only a steam pipeline from the steam collector toward a kraft paper machine. Efficiency is expressed as a ratio of energy delivered to the final users versus an energy at the steam pipe entrance:

$$\eta = \frac{q_{ou}}{q_{in}} = \frac{\sum_{i=1}^{n} \dot{m}_i \cdot h_i}{\dot{m}_{in} \cdot h_{in}} \qquad (1)$$

where, q (W) is heat transfer rate, $\dot{m}$ (kg/s) is mass flow rate, h (J/kg) is enthalpy and subscripts are: ou – outlet, in – inlet, n - number of steam user.

Mass transfer rate at the outlet is determined from capacity of a kraft paper machine while enthalpy is determined from steam pressure and temperature. Hence, energy at the pipe outlet is determined from steam mass flow and steam parameters, needed for the proper machine work (Reid, 1987). Heat transfer rate at the inlet is:

$$q_{in} = q_{ou} + q_{t\_loss} \quad (2)$$

where, q_{t_loss} (W) is total heat transfer loss from the steam pipe to the surroundings and it is a sum of heat transfer loss from bulk steam to the outlet and radiation loss from outer surface to the outlet.

Heat transfer loss could be expressed as (Turner & Doty, 2006):

$$q_{t\_loss} = q_o + q_{rad}; \quad q_o = (t_{st,b} - t_{sur})U_{in}A_{in} \quad (3)$$

where: $t_{st,b}$ (°C) is bulk steam temperature, t_{sur} (°C) is temperature of surroundings, U (W/m^{2}K) is overall heat transfer coefficient based on inner pipe surface A_{in} (m^2).

Overal heat transfer coefficinet is expressed as:

$$U_{in} = \frac{1}{\frac{1}{h_{in}} + \sum_{j=1}^{m} \frac{A_{in}}{2\pi k_j L} \ln \frac{r_{j,ou}}{r_{j,in}} + \frac{A_{in}}{h_{sur} A_{in}}} \quad (4)$$

where: h (W/m^{2}K) is heat transfer coefficient, k (W/mK) is heat conduction coefficient and r (m) is diameter. Subscript j denotes a number of layers which conducts heat. For example, for pipe covered with insulation the number of layers is two, first layer is pipe and ste second is insulation.

Radiation loss, q_{rad}, is calculated from the well known Stefan-Botzman's law (Cao, 2009).

4. RESULTS

In this chapter, results for the energy efficiency are presented. First, efficiency for the actual state is calculated under assumption that 200 m of pipe is completely uninsulated, 400 m of insulation is exposed to rain and moisture and 400 m od pipe is covered with insulation which thickess is 100 mm. It is assumed that heat transfer coefficient from outside surface to the surrounding is h_{sur}=100 W/m^{2}K. Heat conduction coefficient of pipe is 103,82 W/mK and of insulation is 0,09 W/mK. Since wet insulation conducts more heat than dry and undamaged insulation, its heat conduction coefficient is approximatelly 0,36 W/mK. Heat transfer coefficient is calculated from a Dittus-Boelter equation (Perry, 1999). Emmitance from the outer surface to the surrounding is taken from a literature (ASHRAE Handbook -Fundamentals, 2009).

During the calcuation of the heat losses, the temperature of the pipe surfaces are calculated and values are shown in Table 1. The inner pipe surface of uninsulate pipe has temperature 82,3 °C, which is smaller that steam saturation temperature. Apparently, condensation of steam takes place, hence heat transfer coefficients increases for several times. Also, a layer of condensate created onto inner pipe surface, has to be included into overall heat transfer calculation. The pipe fouling was not taken into account since steam is considered as clean

Total heat transfer loss from the steam pipe to the surroundings, while condensation on the uninsulated pipe takes place, is q_{t_loss}=2.730,9 kW. Energy consumption of the kraft paper machine is a product of steam mass flow rate and steam enthalpy. Steam mass flow rate is limited with minimal machine consumption and it is 1,972 t/hour. Hence, energy at the pipe outlet is q_{ou}=1.532,90 kW. Energy at the inlet, calculated from Eq.(2) is q_{in}=4.262,90 kW and energy efficiency calculated from Eq.(1) is 35,9 %.

	Inner pipe surface	Outer pipe surface	Insulation outer surface
Uninsul.	82,3 °C	81,4 °C	-
Wet insulation	252,9 °C	252,8 °C	17,6 °C
Insulated	261,8 °C	261,7 °C	13,5 °C

Tab. 1. Surface temperatures for the actual state

	q_{ou}, (kW)	q_{in}, (kW)	η, (%)
Actual	1531,9	4262,9	35,9
Improved	2332,67	2466,69	94,6

Tab. 2. Energy efficiency values for actual and new state

Steam velocity at the pipe inlet is 26,3 m/s, and at the outlet is 8,09 m/s. These values are small, compared to the allowed values (Turner & Doty, 2006). Therefore, pipe is oversized.

Small values for energy efficiency and steam velocities suggests that actual pipe should be completly removed and other, with smaller diameter, has to be installed.

New pipe is selected due to the minimum allowed steam velocity of 30 m/s. Pipe with inner diameter 80 mm, wall thickness 4 mm and heat conduction coefficient 62,3 W/mK, is selected. It is assumed that pipe is completely covered with Cellular glass insulation, thickess 75 mm with heat conduction coefficient 0,084 W/mK.

Hence, total heat transfer loss is q_{t_loss}=134,02 kW while energy at the outlet is q_{ou}=2.332,67 kW. Energy at the steam pipe inlet is q_{in}=2.446,7 kW, and energy efficiency is now 94,6 %.

Comparison of energy efficiencies for acutal state and improved one, are shown in Table 2.

Price of insulation is approximatelly 9.343,164 Eur for 1000 meter pipe. The price for the pipe material is 17.687,16 Eur. With taxes included, total investments costs are 33.500,00 Eur. Steam savings are 2.778,61 tons/year, which presents savings of approximatelly 15.017,38 Eur/year (based on the assumption that steam price is 2,45 Eur/453,6 kg).

5. CONCLUSION

In this paper the methodology for energy efficiency calculation for steam pipeline is shown. Actual efficiency for the selected case study is calculated, and it is only 35 %. The results have shown that pipeline is oversized and heat losses from the pipeline to the surrounding are tremendous. Solution is to instal completely new pipeline with smaller diameter which should be completely insulated in order to reduce heat losses. Energy efficiency for this new pipeline is 94,6 %. Cost analysis has shown that investments costs for new pipeline are 33.500,00 Eur, while energy savings are 15.017,38 Eur/year. These values show that this investment would be payed-off within 3 years, which is considered as a payable investment.

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