RECOVERY OF COMPRESSOR WASTE HEAT IN ORGANIC RANKINE CYCLE

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Abstract - The paper deals with the recovery of waste heat arising during air compression in a screw compressor ALUP LARGO 90 kW. This compressor was fitted with temperature and pressure sensors to determine the energy balance of the facility. Waste heat quantities were determined in dependence on the compressor output set-ups, to be subsequently used in the Organic Rankine Cycle system.

Keywords - Compressor, Energy, Waste Heat, Organic Rankine Cycle.

I. INTRODUCTION

The production of compressed air is a process intense in energy but low in efficiency [1,2]. Up to 75 % of the energy needed for air compression is converted to heat, which is wasted. In rare cases the heat is used to heat buildings in winter or to heat water.

The research deals with the recovery of waste heat from air compression in Organic Rankine Cycle (ORC), being a conventional condensation cycle. However, instead of water vapour, an organic substance is used as the medium [3]. Based on the type of the facility, this medium drives the turbine, for example, which generates electric power in the generator [4]. An organic substance is used as the medium because of low temperature drops and temperature levels, where the use of water vapour is excluded. The advantages of ORC are the automated technology and minimum maintenance [5].

II. MEASURING STAND

The "measuring stand" comprises of four components: ALUP LARGO 90 kW compressor station (Fig. 1), fittings for the air inlet and outlet, compressed air of the appliance, and the measuring system. The different process parameters of the compressor station were selected to simulate real operation conditions, namely the construction elements, air-handling inlet elements, the outlet section, compressor unit case, including the cooling circuit.

The compressor station was fitted with an inlet and outlet port and sensors. However, its function was not modified. We aimed to collect data without exerting any influence on the measured quantities in the important points of the system. The different sensors were located in order to record the major operation parameters and quantities in the important points of the overall system. This way, we were able to evaluate medium flow rates, temperatures and consumptions of the different nodes.



Figure 1: ALUP LARGO 90 Kw compressor.

The appliance was an air chamber of 500 l in volume, fitted at the inlet with two slide valves and pressure valve with a control range from 9 to 2 bar. Thanks to the system, we were able to alter the consumption of compressed air from the compressor and, thus, to simulate the real needs of the operation in the conditions of the industry and other applications.
The system of sensors is connected to the measuring distributor, where the data measured in real time during the testing operation go to the data-logger Ahlborn Almemo 710 via the measuring interface WASBORN. The data processed in the data-logger are visualised in a PC software. A PC is also used to regulate the basic quantities of the system – e.g. cooling liquid pump in the oil / water circuit.
Before own measurements, it is necessary to make sure the "measuring stand" runs without any problems to avoid undesirable operation trends and potential system damage. When the compressor station is switched on and pre-pressurised, the required pressure is set using the reduction valve and slide valves downstream the air chamber. Thanks to the regulation elements of the pump, the required temperature is set on the oil return into the oil/ water cooler. Next, it is important to steady the system to reach the required /

operational parameters to be able to carry out the measurements. The approximate time to reach the steady state varies in dependence on the required and set operational parameters, and may last tens of minutes. Therefore, the stabilisation time was set to 1 hour in order to prevent possible breakdowns. The time of measurements was also set to 1 hour. After the measurements, the different energy balance flows were evaluated - see Fig. 2.

Based on the compressor energy balance results, we evaluated the waste heat production and proposed the subsequent ORC.

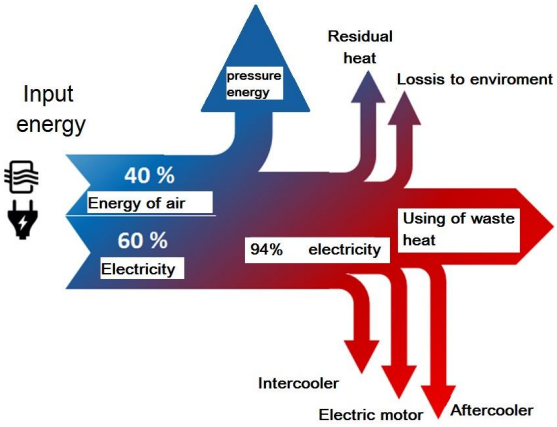


Figure 2: Scheme of the different energy balance flows.

A. Location of the measuring points in the "measuring stand"

The measuring points were selected to determine the energy flows as accurately as possible – see Fig. 3. When determining the air flow in the ducts (air speed), it is important to position the measuring points correctly. These were determined using a set of measurements during which, using Prandtl tube measuring of air ports, each point of average speed was determined. Calorimetric anemometer sensors were placed at each of the points. The points were verified by subsequent measurements.

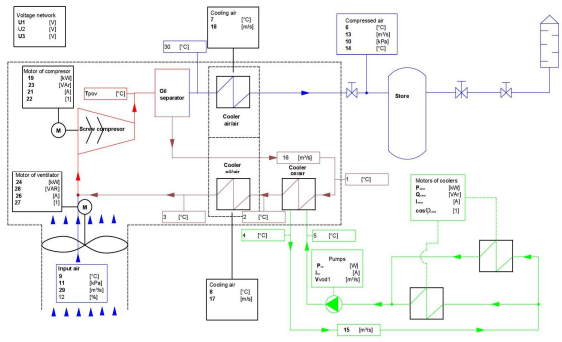


Figure 3: Scheme of the measuring equipment set-up.

Fig. 3. shows the scheme of the measuring points: green – water; blue – compressed air, intake; red – water + oil, dark red – oil.The different energies were determined according to Equation 1. Enthalpy and densities for the different states and substances determined using the EES programme.

$$E_x=(m_x)\cdot i_xTp \quad (1)$$

where: E_x – energy of component x

(m_x)˙ – mass flow of component x

i_xTp – enthalpy of component x at temperature T and pressure p

III. DETERMINATION OF A COMPRESSOR ENERGY BALANCE

The energy balance was determined for the ALUP LARGO 90 kW compressor (Fig. 1). Having fitted the temperature and pressure sensors and connected to the control system, we carried out a series of measurements under various output set-ups. The heat arising from the air compression was passed into the water circuit via the oil/ water exchanger. The compressor output is 14.3 m^3/min and the maximum quantity of exploitable heat was determined as 74 kW. There were several complications during the testing of the different parameters. It was utmost difficult to determine the air flow rates. These were verified by means of Prandtl tube measuring. To measure the speed of air flow and compressed air volumes, we used the method of Prandtl tube measuring combined with a mercury U-tube. The measurements of oil flow rates were burdened by a considerable error caused by the formation of bubbles, which influenced the final values of the fitted flowmeter. Despite all the complications, the energy balance of the compressor was determined for its different output set-ups.

The below stated energy balance states the balance between the energies entering the facility and leaving the facility in kW.

$$E1+ PK+ PV = E2+ E3 + E5+ QV+ EZ \quad (2)$$

where: E1 - energy of the inlet air

PK - compressor input

PV - fan input

E2 - inlet air energy (air/ air exchanger)

E3 - compressed air energy

E5 - outlet air energy (oil/ air exchanger)

QV - energy in the cooling water (oil/ water exchanger)

EZ - energy of the losses

For illustration, we calculated the energy balance of the compressor at the air compression set-up of 5 bar. The values are given in kW.

$$179+ 82.5+ 0{,}004 = 91+ 29 + 84.7+ 52.6+ 4.1 \quad (2)$$

The energy balance implies that at the compressor output set-up of 5 bar, the quantity of the heat

exploitable in the ORC system is 52.6 kW. The determined quantities of the exploitable heat in dependence on the compressor set-up are given in the chart in Figure 4 below.

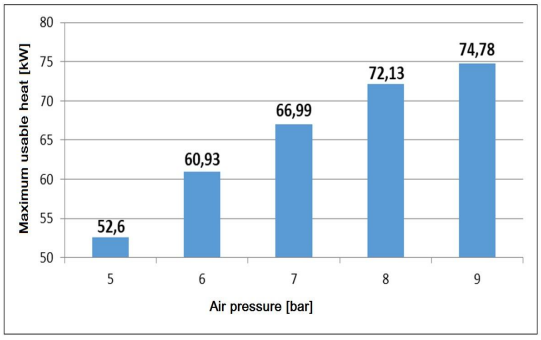


Figure 4: Chart of the dependence of the exploitable heat quantity on the compressor output.

IV. ORC SYSTEM DESIGN

The Organic Rankine Cycle system was proposed on the basis of the model in the EES programme. We selected the relevant cooling agents, using which the efficiency of the overall system will be tested. When selecting the cooling agents, we assessed the parameters such as T-S diagram, toxicity, minimum environmental impact, availability in the EU, and the price. We expect to use both the screw and scroll expanders and the output measurements will be carried out using a dynamometer. The expected heat recovery from the exploitable compressor heat will be up to 10% based on the low-temperature ORC system efficiency.

CONCLUSION

The recovery of waste heat arising from air compression using an ORC system is an innovative direction of research. Considering the fact that compressor stations use several tens of compressors of outputs analogous to the compressor used in this research, it is a huge potential energy source with a number of applications. The paper reports research using ALUP LARGO 90 kW compressor fitted with a number of sensors and control system, together representing a “measuring stand”. Using the “measuring stand” we determined the energy balance for the different compressor output set-ups. The major focus was to recover the energy from the waste (exploitable) heat, which was determined for all the compressor output set-ups. It shows that at the maximum compressor output, it is possible to recover as much as 74.7 kW of energy in the ORC system. The energy recovery and its possible applications will be the subject of the subsequent research.

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