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# DETERMINATION OF THE AMOUNT OF USABLE WASTE HEAT IN THE PRODUCTION OF CORRUGATED CARDBOARD

# URČENÍ MNOŽSTVÍ VYUŽITELNÉHO ODPADNÍHO TEPLA PŘI VÝROBĚ VLNITÉ LEPENKY

**Abstract**

Machines producing corrugated cardboard draw large amounts of thermal energy in the form of steam. In the Czech Republic, there are many such factories. This article deals with finding suitable parts of machines for the production of corrugated cardboard, from which the waste heat can be used, and determining the amount of heat.

**Abstrakt**

Stroje vyrábějící vlnitou lepenku mají velkou spotřebu tepelné energie ve formě páry. V ČR je mnoho takovýchto závodů. Článek se zabývá nalezením vhodných částí stroje na výrobu vlnité lepenky, ze kterých lze využít odpadní teplo a určením množství tohoto tepla.

**Keywords**

Waste heat, waste heat measurement, potential energy savings, crimping machine, crimping stool, gluing machine,

## 1 INTRODUCTION

With the increasing standard of living, our society grows, and with it the consumption of packaging materials. An important position among packaging materials is occupied by corrugated cardboard (carton). In the Czech Republic, there are a large number of manufacturing companies that are engaged in the production of various kinds of corrugated cardboard. Corrugated cardboard is a technologically complex process that consumes large amounts of energy in the form of water vapor – the most dominant consumption of the whole plant.

The main reasons that corrugated cardboard packaging ranks among the most important in the packaging industry, are:

- Corrugated cardboard is different from other boards in its characteristic structures and properties, which gives it a wavy layer, respectively, fluting.
- Compared with other cardboard, it has a thickness relative to the lowest density, and thereby substantially lowers the consumption of material for a comparable solution to cardboard paper packaging with solid boards.

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- It has very good functional packaging properties, especially the damping ability, flexibility, and relatively high stability, along with good buckling strength (compressive strength of the edge), which are important functional properties of the packaging boxes.
- A significant advantage is that it is fully recyclable after fulfilling the purpose, and also a significant proportion of recycled paper materials are used in the manufacture of the paper and cardboard layers from which it is produced (representing a proportion of 60% or more).

# 2 DESCRIPTION OF THE PRODUCTION TECHNOLOGY

## 2.1 Types of corrugated cardboard

Corrugated cardboard can be distinguished by the number of layers, according to the dimensional proportions of the fluting, according to the waveform, and by the materials used in its manufacture. Different kinds of used corrugated cardboard materials give different mechanical properties, differing basis weight, and even different thicknesses.

Depending on the number of layers, corrugated cardboard is made of (Fig. 1):

- two layers,
- three layers,
- five layers,
- seven layers.

The geometry of the waves are distinguished by the spacing distance of the wave, wave height, and wave shape.

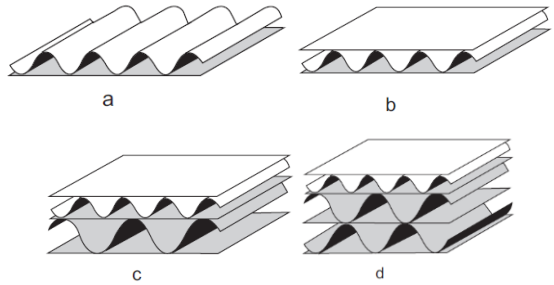


Fig 1. Types of corrugated board: a) two layers, b) three layers, c) five layers, d) seven layers [1]

## 2.2 Production of corrugated cardboard

Two layer corrugated cardboard is manufactured on a single corrugator machine, having a crimping stool. Multi-layer corrugated cardboard is produced on combined machines.

A combined machine for the production of three layer corrugated cardboard can also be equipped for the production of five layer cardboard, which has two crimping stools, or three layer corrugated cardboard, which has three crimping stools. This is very useful equipment, as the production program for these machines usually does not use all of the crimping stools.

Crimping stool combined machines for manufacturing multilayer cardboard can be equipped with modular systems for swapping the crimping rollers. The machine can produce corrugated cardboard with a relatively wide range, in combinations of both types of waves in three layer and multi layer boards too.

## 2.3 Parts of the machine for the production of corrugated cardboard (crimping machine)

The following illustration a simplified diagram of the combined corrugating machine with two stools. The following is a description of each part of the machine as shown in Fig. 2.

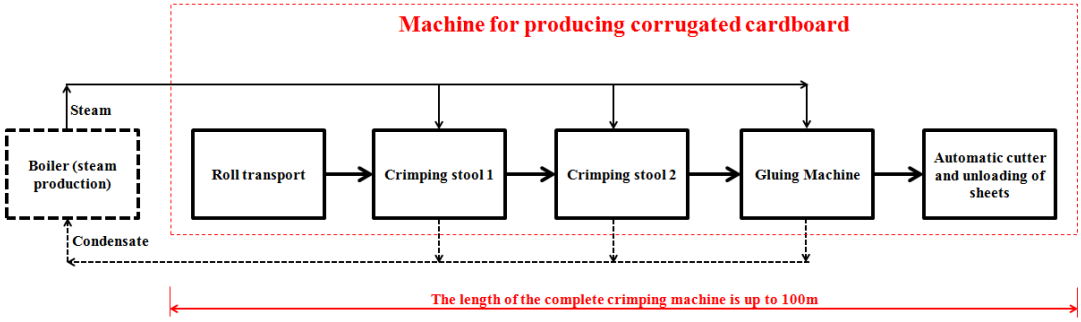


Fig 2. Simplified diagram of the combined fluted corrugating machines with two stools

### 1) Boiler (steam production)

The boiler is not a direct part of the machine for the production of corrugated cardboard, but it needs to run a lot of steam. The boiler supplies the steam for crimping machine within the temperature 194 to 198 °C, and a pressure of 1.3 to 1.6 MPa. The entire amount of steam is returned to the boiler in the form of pressure condensate at a temperature of about 160 °C. Only when approaching the machine, or in some non-standard conditions (pressure relief valve), is it returned to the supply tank as a low pressure condensate. The consumption of tons of steam by the crimping machine varies, depending on the produced cardboard and the construction machinery. It usually ranges from 2 tons per hour for simple cardboard, to 5 tons per hour of steam for cardboard which involves crimping stools. The machines are heated before production for 40 to 60 minutes.

### 2) Roll transport

Rolls of paper for the production are transported by the lever arm of the unwinder of the machine to provide continuous conveyors for the rolls. The cycle of removal of processed rolls (tubes) and the deployment of new blades into the operating position takes 15 seconds.

### 3) Crimping stool 1 and 2

This is equipped for either one type of waves, a modular system for two types, or a plug system running rollers for other types of waves. The modular system allows conversion of the module for the second type of waves.

On one side is a band of paper that is later processed for the middle layer, then led to a crimping stool. Powered by the pre-steamer, which is heated by means of steam-heated cylinders. In the steam humidifier, a band of paper is sprayed with steam, and thus improves its behaviour when forming. It then passes through heated rotating crimping rollers, which are interlocking. Such crimping rollers form a corrugated middle layer. This middle corrugated layer then goes through the upper corrugator roller, and at the peaks of the waves is a glue applicator roller, gluing in the stool. The air in the stool has overpressure, which means that the middle layer can not fall from the crimping rollers. On the other side of the crimping stool, another paper band is fed in. Also, this is heated in a preheater, and a steam heated cylinder at the upper side of the crimping rollers sticks it to the middle layer, creating two layer cardboard. According to the desired production (number of waves), either one crimping stool works, or both [2].

**4) Gluing Machine**

The gluing machine has an inlet preheat cylinder (cylinder), which compensates for preheating the moisture content in the paper or cardboard, and has a controllable surface of the wrap envelope, which affects the moisture content of the material processed. The adhesive applicator applies adhesive to a rasterized cylinder, whose geometry defines the rasterization quantity of glue on the tops of the transmitted waves for bonding the three layer or five layer cardboard.

Then follows the pressure system for the board across the entire band to heated flat plates (drying section). The active length is adjustable, depending on the machine speed and quality of the cardboard. It provides uniform bonding of the layers of cardboard, while ensuring the required flatness.

**5) Automatic cutter and unloading of sheets**

The cutter cuts the cardboard strip across the width of the machine into sheets, and loads them in a stack.

The automatic unloading of sheets (pieces) is programmatically controlled, based on the function of the sheet cutters. Each sheet (cut) is quickly and accurately moved with vacuum (suction) onto the unloaders, which are also equipped with vacuum holders. Then, they are moved to a sheet unloading conveyor, which loads them into stacks on pallets.

## 3 WASTE HEAT FROM THE CRIMPING MACHINE

The crimping machine consumes a large amount of thermal energy in the form of steam. Annual consumption of heat by the crimping machine is dependent on the production and the type of machine. On the order of up to 20,000 GJ/year for a crimping machine with two stools.

The crimping machine is composed of parts, see Fig. 2 Individual parts are placed into one functional unit that is up to 100 m long, and in one long hall.

Thermal energy is used in the crimping stools (machines for producing five layer cardboard have two modular crimping stools) and in the gluing machine.

### 3.1 The crimping stool

The crimping stools are located in so-called cabins, which insulate the sound of the crimping stool, and also prevent the migration of fine paper fibres and moisture that is released into the hall during crimping, see Fig. 3.

Fig 3. View the crimping stool cabin

In the cabins, during production the temperature can reach up to 60 °C. Holes in the ceiling of the cabin serve to release the heat, see Fig. 4 and 5. From these holes, with the aid of fan ventilation ducting, hot exhaust air is carried to the air outlet/extractor on the roof of the hall. The extractor leads to the outside skylight, and at six-month intervals, is cleaned of impurities. Fresh air is drawn from outside the cab, i.e. from the production hall.


Fig 4. View inside the cab

Fig 5. Hole for exhaust air from the cabin

## 3.2 Gluing machine

The gluing machine, as regards heat energy consumption of the entire crimping machine, shares according to data obtained from measurement, operating at an average of 16 %. This value

varies depending on the type of production in the range 10-22 %. The gluing machine consists of a preheater and three steam heated drying sections, in which different temperatures and pressures are maintained, depending on the type of corrugated cardboard produced.

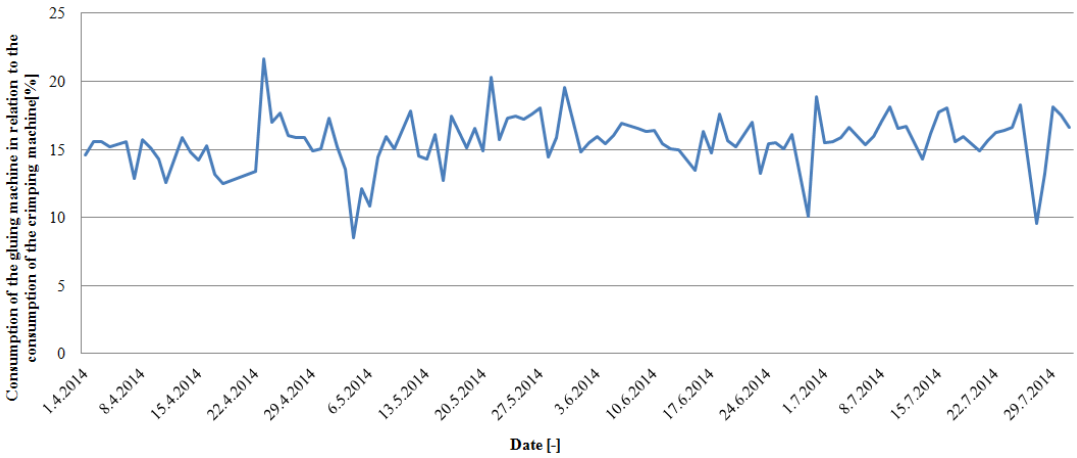


Fig 6. Consumption of the gluing machine in relation to the consumption of the crimping machine

The gluing machine is equipped with only the side panelling for safety reasons, see Fig. 7 and 8. Heat released in the process of bonding and drying escapes into the hall, and in the winter months it is used for heating the building. Air temperatures measured above the drying sections are between 40 to 50 °C. This heat is thus already in use. Utilization can be optimized by using air ducts with fans that would use the heat from the crimping machine hall and distribute it to other parts of the factory.

Due to the ratio of the total heat consumption of the crimping machine that goes into the gluing machine, investment in equipment that this heat at low temperature uses would not be worthwhile.

Fig 7. Side view of the drying section of the gluing machine

Fig 8. Top view of a gluing machine

# 4 MEASUREMENT OF EXPELLED WASTE HEAT FROM THE CRIMPING STOOL

All unused waste heat from the crimping machine comes from the crimping stool cabin. To determine the amount of usable waste heat from the crimping stool, a series of measurements at different operating conditions was selected by the industrial company. The measured crimping machine had two crimping stools, from which the cabin air is discharged through the air outlets on the roof.

## 4.1 Measuring method and instruments used

Air flow was measured using a Prandtl speed dynamic Airflow probe with an elliptical head, with dimensions 1523 mm × 9.5 mm, connected to an FDA602S1K differential pressure sensor, measuring range ±1250 Pa, connected to an ALMEMO 2690 AHLBORN universal measuring instrument. Air flow was measured using the network method, according to the manufacturer's instruction manual for the probe [3].

The temperature was measured using a jacketed type "K" compensating cable thermocouple, connected to an AHLBORN ALMEMO 2690 universal measuring instrument.

Barometric pressure was measured using an FDA612SA atmospheric pressure transducer, connected to an AHLBORN ALMEMO 2690 universal measuring instrument.

The dew point temperature, density, and relative humidity of flowing air were measured using an FNA846 psychometric probe, connected to an AHLBORN ALMEMO 2690 universal measuring instrument.


Fig 9. Designation of the air outlets of the crimping stools

Fig 10. Photos from during measurement

## 4.2 Results of measurement

The average measured and calculated values of the four measurements performed are listed in **Tab. No. 1** for each of the crimping stools separately.

**Tab. 1** Measured and calculated values

| | | | **Crimping stool no. 1 - Average values** | **Crimping stool no. 2 - Average values** |
|---|---|---|---|---|
| $p_{bar}$ | Barometric pressure | **[kPa]** | 98.00 | 98.00 |
| $t_o$ | Surrounding temperature | **[°C]** | 22 | 22 |
| $D$ | The inner diameter of the channel | **[mm]** | 610 | 610 |
| $S$ | The flow area of the channel | **[$m^2$]** | 0.292 | 0.292 |
| $\Delta p_{st}$ | The static pressure of air rel. | **[Pa]** | 20 | 20 |
| $p_{st}$ | The absolute static pressure of air | **[kPa]** | 98.02 | 98.02 |
| $t$ | Temperature of air | **[°C]** | 47.5 | 47.5 |
| $t_{RB}$ | Dew point of air | **[°C]** | 35.40 | 35.40 |
| $d_1$ | Specific humidity of air | **[g·$kg^{-1}$]** | 38.90 | 38.90 |
| $\phi_1$ | Relative humidity of air | **[%]** | 52.90 | 52.90 |
| $\phi 1$ | Absolute humidity | **[g·$kg^{-1}$]** | 26.90 | 26.90 |
| $i_1$ | Specific enthalpy of air | **[kJ·$kg^{-1}$]** | 148.50 | 148.50 |
| $\rho_N$ | Normal density of air | **[kg·$m_N^{-3}$]** | 1.22 | 1.22 |
| $\rho_{ef}$ | Effective density of air | **[kg·$m^{-3}$]** | 1.00 | 1.00 |
| $w$ | The mean velocity of air | **[m·$s^{-1}$]** | 15.05 | 13.54 |
| $V_{ef}$ | Volumetric flow rate of air in an efficient state | **[$m^3$·$s^{-1}$]** | 4.39 | 3.95 |
| $V_N$ | Volumetric flow rate of air in the normal state | **[$m^3_N$·$s^{-1}$]** | 3.62 | 3.26 |
| $m$ | The mass air flow (effective) | **[kg·$s^{-1}$]** | 4.40 | 3.96 |
| $m$ | The mass air flow (effective) | **[kg·$h^{-1}$]** | 15840 | 14256 |

Although this is one crimping machine, calculations are made for each of the crimping stools separately. The measurement was carried out with simultaneous operation of both crimping stools. This situation does not always occur. When producing three layer cardboard, only one crimping stool is in operation. The second crimping stool joins only when necessary for the production of five layer cardboard. The total potential energy must be determined with regard to the operating hours of the individual stools, and not only due to the operating hours of the entire crimping machine.

Calculation of the usable power is calculated for three cases, namely:

- cooling the air to the dewpoint,
- cooling air to 20 °C,
- cooling air to 15 °C.

Calculated values of usable power for crimping stools are shown in tables 2 and 3.

**Tab. 2** Calculated values for crimping stool No. 1

| | | | Crimping stool no. 1 - Average values | | |
|---|---|---|---|---|---|
| | | | **Cooling to the dewpoint** | **Cooling to 20 °C** | **Cooling to 15 °C** |
| $\Delta\tau$ | The temperature difference of air before and after the cooling | **[°C]** | 35 | 28 | 33 |
| *d2* | Specific humidity of air after cooling | **[g·kg$^{-1}$]** | 38.90 | 7.95 | 5.78 |
| $\phi$*2* | Relative humidity of air after cooling | **[%]** | 100.0 | 100.0 | 100.0 |
| *i2* | Specific enthalpy of air after cooling | **[kJ·kg$^{-1}$]** | 135.4 | 118.8 | 113.4 |
| $\Delta\delta$ | The amount of precipitated water | **[g·kg$^{-1}$]** | 0.0 | 31.0 | 33.1 |
| $\Delta\delta$ | The amount of precipitated water | **[g·s$^{-1}$]** | 0 | 136 | 146 |
| $\Delta\delta$ | The amount of precipitated water | **[kg·h$^{-1}$]** | 0 | 490 | 525 |
| *P* | Power | **[kW]** | 58 | 131 | 154 |

**Tab. 3** Calculated values for crimping stool No. 2

| | | | Crimping stool no. 2 - Average values | | |
|---|---|---|---|---|---|
| | | | **Cooling to the dewpoint** | **Cooling to 20 °C** | **Cooling to 15 °C** |
| $\Delta\tau$ | The temperature difference of air before and after the cooling | **[°C]** | 35 | 28 | 33 |
| *d2* | Specific humidity of air after cooling | **[g·kg$^{-1}$]** | 38.90 | 7.95 | 5.78 |
| $\phi$*2* | Relative humidity of air after cooling | **[%]** | 100.0 | 100.0 | 100.0 |
| *i2* | Měrná entalpie vzdušiny po ochlazení | **[kJ·kg$^{-1}$]** | 135.4 | 118.8 | 113.4 |
| $\Delta\delta$ | The amount of precipitated water | **[g·kg$^{-1}$]** | 0.0 | 31.0 | 33.1 |
| $\Delta\delta$ | The amount of precipitated water | **[g·s$^{-1}$]** | 0 | 123 | 131 |
| $\Delta\delta$ | The amount of precipitated water | **[kg·h$^{-1}$]** | 0 | 441 | 472 |
| *P* | Power | **[kW]** | 52 | 118 | 139 |

Aspirated air mass from areas of the crimping stools carries a relatively large amount of energy, partly due to the substantial heat in the air, but mainly due to a significant proportion of moisture contained in the air mass.

For example, when cooling gaseous fluid at a temperature of about 20 °C and a precipitation of moisture, it is possible, with simultaneous operation of both the crimping stools, to obtain about 250 kW of thermal energy.

## 5 TOTAL POTENTIAL ENERGY SAVINGS

Based on the operating hours of each crimping stool, we can determine the total potential energy which can be used for a year. Last year, crimping stools No. 1 and No. 2 were in operation for 3010, and respectively 2340 hours. From this data we can, be according to formula (1), calculate the potential energy savings when using a suitable heat exchanger, which would cool air to 20 °C. Calculated values are shown in Table No. 4.

$$E = \dot{E} \cdot t \cdot 0.0036 \tag{1}$$

where:

$E$ – annual thermal energy [GJ],

$\dot{E}$ – usable power of crimping stools when cooled to 20 °C [kW],

$t$ – annual operating hours of a crimping stool [h].

**Tab. 4** Table of calculated usable energy

| | **Operating hours** | **Power when cooled to 20 °C** | **Annual energy** |
|---|---|---|---|
| | **[h]** | **[kW]** | **[GJ]** |
| Crimping stool 1 | 2340 | 131 | 1103.5 |
| Crimping stool 2 | 3010 | 118 | 1278.6 |
| **Total** | - | - | **2382.2** |

The calculations show that crimping stool No. 1 can use about 1100 GJ/year. From crimping stool No. 2 we can use about 1280 GJ/year. The total potential energy savings using waste heat from the the crimping stools when cooling the exhaust air to 20°C is approx. 2380 GJ/year.

For the purpose of using waste heat from the the crimping stools, it is necessary to use a special heat exchanger, allowing the use not only of felt heat the air, but also latent heat from condensation, and moisture wicking a considerable amount of condensate (when cooled to 20 °C cca $150 \div 200$ kg·h$^{-1}$).

The extracted air mass contains certain operating conditions with an unspecified concentration of cellulose fibers and other impurities, including sticky resin (Fig. 11). It is therefore necessary to ensure clean heat transfer surfaces of the heat exchanger.

An appropriate use of waste heat is for a hot water air heating system, for air systems. This option does not address the need for heat in the summer months. A constant need is to keep the heat needed for hot water. However, this solution includes the need to increase the heat potential of the heat transfer fluid to a temperature for hot water. One option is to use a thermal cycle heat pump.

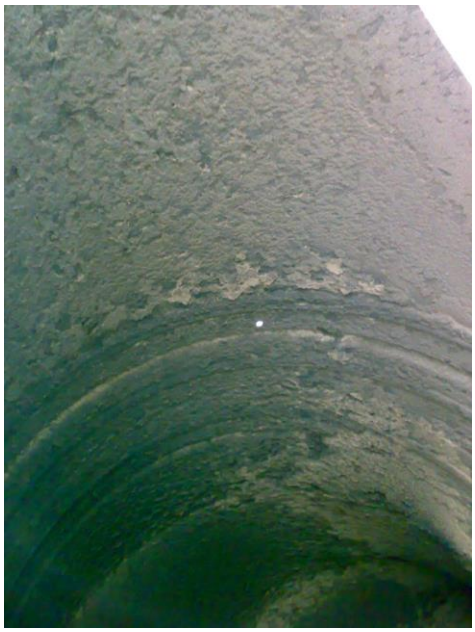

Fig 11. View of the deposits on the inner wall of the exhaust of crimping stool No. 1

## 6 CONCLUSION

On the basis of the measurements, we calculated the annual energy savings of the crimping machine when cooling the exhaust air to 20 °C as being approx. 2380 GJ/year. Such an amount would, with the total annual consumption of the crimping machine at 20,000 GJ, be approx. 12 % of the consumed heat energy. Use of this heat is complicated due to the impurity content, low temperature, and high humidity in the exhaust air. For it to be suitable for year-round use of waste heat of these parameters, it would be necessary to use a special heat exchanger.


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