GÉPÉSZET '98

PROCEEDINGS OF FIRST CONFERENCE ON MECHANICAL ENGINEERING

Volume 2

Technical University of Budapest
May 28–29, 1998.

OPTIMIZATION OF THE OPERATION OF SUGAR-DRYING EQUIPMENT FOR DIFFERENT SUGAR INPUT

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Summary

The closing technological steps of the sugar-making process are the decreasement of the moisture and temperature of the outgoing sugar from spin-dryer. These steps are made in the Roto-Louvre type cylinder-dryer. The aims of drying and cooling are to decrease the moisture and temperature of the sugar to be stored for a middle length of time in silos. Drying-cooling is made using warm and cools air. The operation of dryer and the processes of the science of heat have been described in [4]. In this paper we would like to show a procedure, how to optimise the operation of the drying equipment due to minimise the energy used for it. The processes of the science of heat, which were described mathematically, are built into the optimization algorithm. We have applied the procedure for different input of sugar.

Lists of symbols and subscripts are as follows:

Symbols:
- $\dot{m}$ [kg/s] mass flow,
- q [m³/s] volume flow,
- t [°C] temperature,
- T [K] absolute temperature,
- p [Pa] absolute pressure,
- P [W] performance,
- x [kg/kg] moisture relating to the mass of dry air,
- ξ [kg/kg] moisture relating to the mass of wet sugar,
- $\dot{Q}$ [J/s] heat flow,
- r [J/kg] hidden heat,
- c [J/(kgK)] specific heat,
- R [J/(kgK)] gas constant.

Subscripts:
- c: sugar,
- m: warm air,
- h: cold air,
- b: incoming,
- k: outgoing,
- 1,2: cross-sections,
- t: axis,
- f: heating,
- o: environment,
- a: relating to 20°C,
- s: drying,
- z: cooling,
- p: constant pressure,
- g: steam,
- v: water,
- tel.: saturated.

The working scheme of sugar-drying cylinder is visible in Fig.1. The wet sugar input is at the left side of the sugar-drying cylinder. First it contacts with the warm air. Most part of the sugar's moisture is given to this air, while its temperature is decreasing. At the right side of the sugar-drying cylinder the incoming cold air under the sugar decreases its temperature. The heat-power engineering model is described in [4].

The problem to be solved using these heat considerations to do the drying and cooling of the sugar using the smallest energy. We should do this using the environmental air, what is available.

The total performance to be minimised is as follows:

$$P = P_f + P_{tm} + P_{th} + P_{u}. \qquad (1)$$

In Eq. 1 the performances are the following:

- The thermal performance of the warm air in the heat exchanger:

$$P_f = (c_p + c_{pg} \cdot x_m) \cdot \dot{m}_m \cdot (t_m - t_o) \quad , \qquad (2)$$

where $\dot{m}_m = \dot{m}_{m,b} / (1 + x_m)$ the mass of the incoming dry air.

- The axial output of the „warm air" ventilator:

$$P_{tm} = q_m \cdot \frac{T_a}{T_o} \cdot \frac{\Delta p_{\dot{s},m}(q_m)}{\eta_m(q_m)} \quad , \tag{3}$$

where $\Delta p_{\dot{s},m}(q_m)$ and $\eta_m(q_m)$ the total pressure and efficiency curves of the ventilator at temperature T_a.

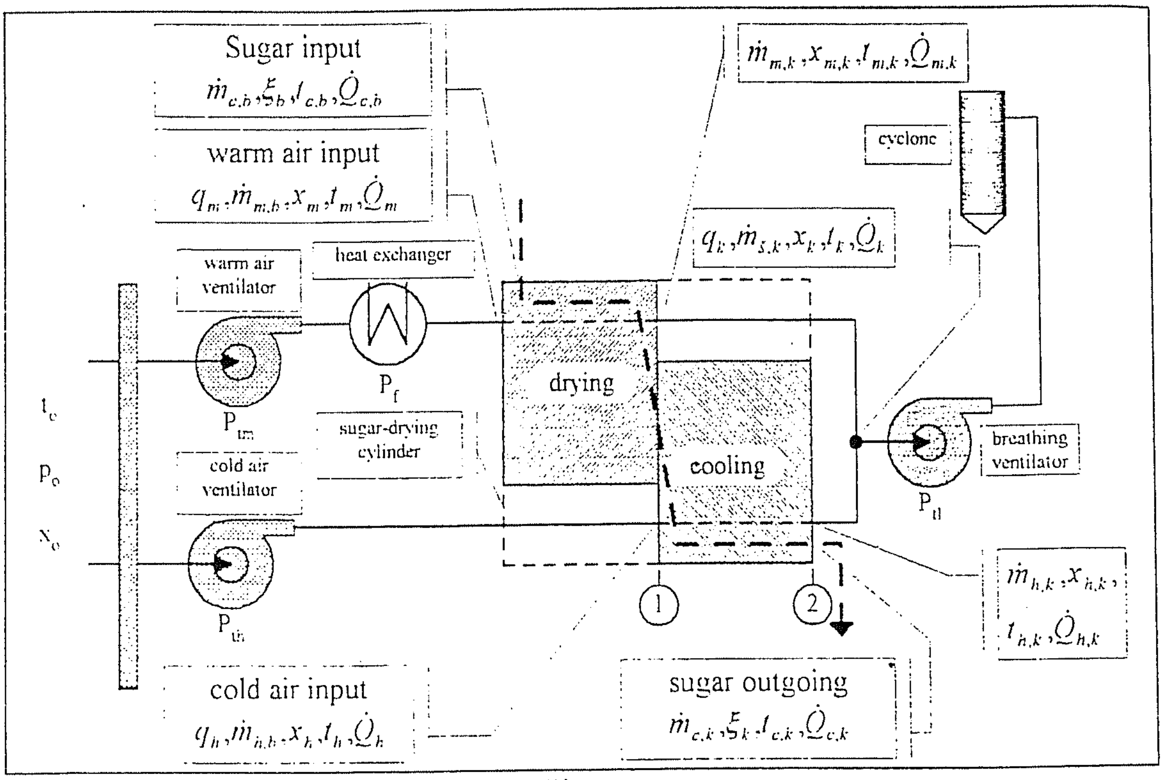

Fig.1.

- The axial output of the „cold air" ventilator is similar:

$$P_{th} = q_h \cdot \frac{T_a}{T_o} \cdot \frac{\Delta p_{\dot{s},h}(q_h)}{\eta_h(q_h)} \quad . \tag{4}$$

- The performance of the breathing ventilator, outgoing from the drying cylinder and incoming to the dust-collecting cyclone:

$$P_{tl} = q_k \cdot \frac{T_a}{T_k} \cdot \frac{\Delta p_{\dot{s},l}(q_k)}{\eta_l(q_k)} \quad . \tag{5}$$

We are looking for the minimum of Eq.1 due to the following circumstances:

■ Given constants:	t_o, p_o, x_o ,	i.e. the environmental properties, where the drying-cooling air comes from;
	$\dot{m}_{c,b}, t_{c,b}, \xi_b$,	i.e. the condition of the incoming sugar.
■ Prescribed data:	$t_{c,k}$,	i.e. the temperature of the outgoing sugar, which is necessary for the long-term storage.
■ Variables:	t_m, q_m ,	i.e. the volume and temperature of the warm air, with upper and lower limits.
■ Constraints:	q_h , q_l , ξ_h ,	i.e. those quantities, which have also upper and lower bounds.

The available formulae from the heat technique model have been described in [6]. Using those formulae we can build a calculation order. The main steps are as follows:

① Heat emission of the sugar during drying:

$$\Delta \dot{Q}_s = k \cdot \dot{m}_{c,b} \cdot (t_{c,b} - t_m) \quad . \tag{6}$$

② Convergent iterative calculation to determine the moisture of the outcoming sugar ξ_k:

$$\xi_k = \xi_b - \left[\frac{1}{r_o} \cdot \left[\frac{\Delta \dot{Q}_s}{\dot{m}_m} + c_p \cdot t_m + x_m \cdot \left(c_{pg} \cdot t_m + r_o \right) - D(\xi_k) \right] - x_m \right] \cdot \frac{\dot{m}_m}{\dot{m}_{c,b}} \cdot (1 - \xi_k) \quad , \tag{7}$$

where:

$$D(\xi_k) = \left[c_p + c_{pg} \cdot \left(x_m + \frac{\dot{m}_{c,b}}{\dot{m}_m} \cdot \frac{\xi_b - \xi_k}{1 - \xi_k} \right) \right] \cdot t_1(\xi_k) \quad , \tag{8}$$

$$t_1(\xi_k) = \frac{\left[c_c \cdot (1 - \xi_b) + c_v \cdot \xi_b \right] \cdot t_{c,b} - \dfrac{\Delta \dot{Q}_s}{\dot{m}_{c,b}}}{\left[c_c \cdot (1 - \xi_k) + c_v \cdot \xi_k \right] \cdot \dfrac{1 - \xi_b}{1 - \xi_k}} \quad . \tag{9}$$

③ The intermediate temperature t_1 can be determinated by the previous iterational process according to Eq. (9).

④ Moisture of warm water at the end of drying process:

$$x_1 = \frac{\dfrac{\Delta \dot{Q}_s}{\dot{m}_{c,b}} + c_p \cdot t_m + x_m \cdot \left(c_{pg} \cdot t_m + r_o \right) - c_p \cdot t_1}{c_{pg} \cdot t_1 + r_o} \quad . \tag{10}$$

⑤ Mass flow of the dry cold air:

$$\dot{m}_h = \dot{m}_{c,b} \cdot \frac{\left[c_c \cdot (1 - \xi_k) + c_v \cdot \xi_k \right] \cdot \dfrac{1 - \xi_b}{1 - \xi_k} \cdot (t_1 - t_2)}{\left[c_p \cdot t_2 + x_h \cdot \left(c_{pg} \cdot t_2 + r_o \right) \right] - \left[c_p \cdot t_h + x_h \cdot \left(c_{pg} \cdot t_h + r_o \right) \right]} \quad . \tag{11}$$

⑥ The mass flow of mixed air leaving the dryer equipment:

$$\dot{m}_k = \dot{m}_m + \dot{m}_h \quad . \tag{12}$$

⑦ The moisture of mixed air leaving the dryer equipment:

$$x_k = \frac{\dot{m}_m \cdot x_1 + \dot{m}_h \cdot x_h}{\dot{m}_k} \quad . \tag{13}$$

⑧ The temperature of mixed air leaving the dryer equipment:

$$t_k = \frac{\dot{m}_h \cdot \left[c_p \cdot t_2 + x_h \cdot \left(c_{pg} \cdot t_2 + r_o \right) \right] + \dot{m}_m \cdot \left[c_p \cdot t_1 + x_1 \cdot \left(c_{pg} \cdot t_1 + r_o \right) \right] - \left(\dot{m}_m + \dot{m}_h \right) \cdot x_k \cdot r_o}{\dot{m}_k \cdot \left(c_p + x_k \cdot c_{pg} \right)} \quad . \tag{14}$$

⑨ The volume of mixed wet air leaving the dryer equipment:

$$\dot{m}_{o,k} = \dot{m}_k \cdot (1 + x_k) \quad . \tag{15}$$

⑩ The in- and outcoming mass flow according to the volume flow:

$$q_m = \frac{\dot{m}_{m,b}}{\rho(t_m, p_m)},\quad q_h = \frac{\dot{m}_{h,b}}{\rho(t_h, p_h)},\quad q_k = \frac{\dot{m}_{\ddot{o},k}}{\rho(t_k, p_k)}, \qquad (16a,b,c)$$

where

$$\rho(t,p) = \left[\frac{p}{R} - \left(\frac{1}{R} - \frac{1}{R_g}\right)\cdot p_{gtel}(t)\right]\cdot\frac{1}{(t+273.15)} \qquad (17)$$

The equations above have built into the optimization system, Hillclimb [4,5]. Using this technique we can calculate the minimum energy consumption, the volume and temperature of warm and cold airs due to given environmental conditions, in- and outgoing sugar temperatures.

In our example the incoming sugar moisture is varies, the followings are constants:

- environmental conditions: $t_o=17.8°C$, $p_o=1,038bar$, $\varphi_o=61.3\%$;
- temperature and moisture of incoming sugar: $t_{c,b}=55°C$; , $\xi_k=0.68\%$;
- temperature of outgoing sugar: $t_{c,k}=34°C$.

Upper and lower limits are as follows:

$0,00018 \le \xi_k \le 0,002$ $\quad 4m^3/s \le q_m,\ q_h \le 9m^3/s$ $\quad 8m^3/s \le q_k \le 17\ m^3/s$.

The results of the calculations can be seen on Fig. 2.,3.,4. and 5.

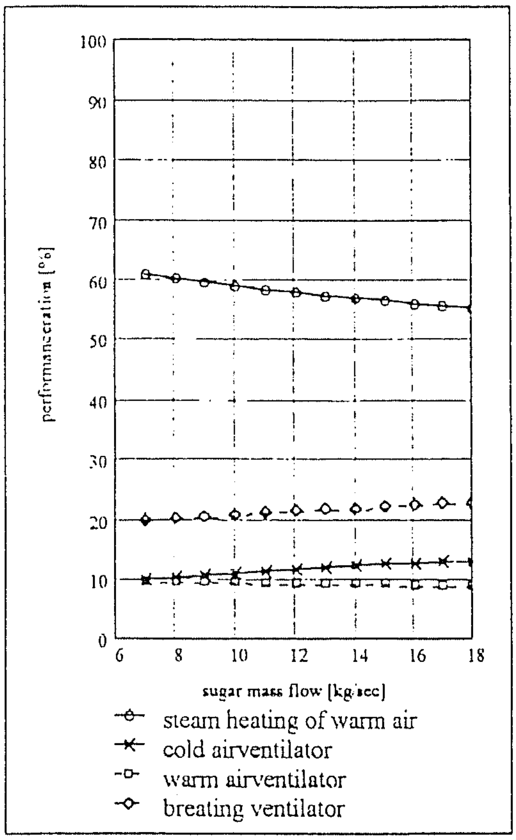

Fig.2.

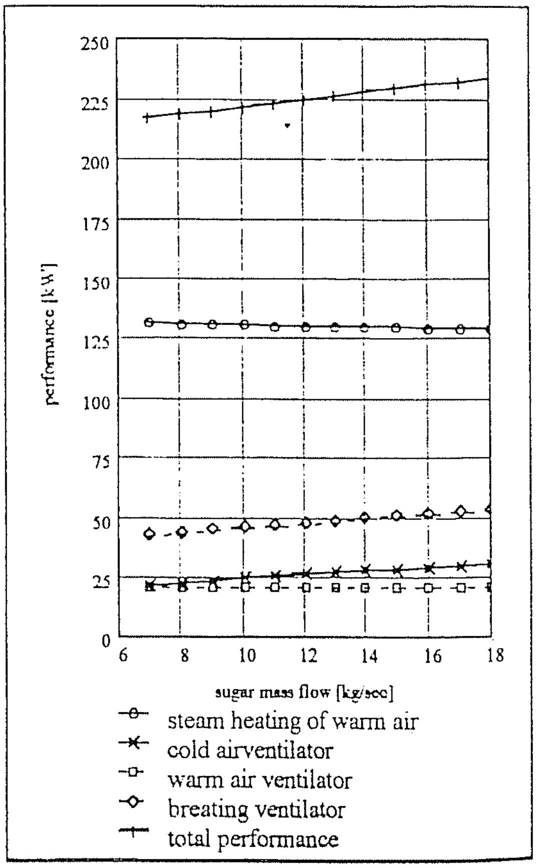

Fig.3.

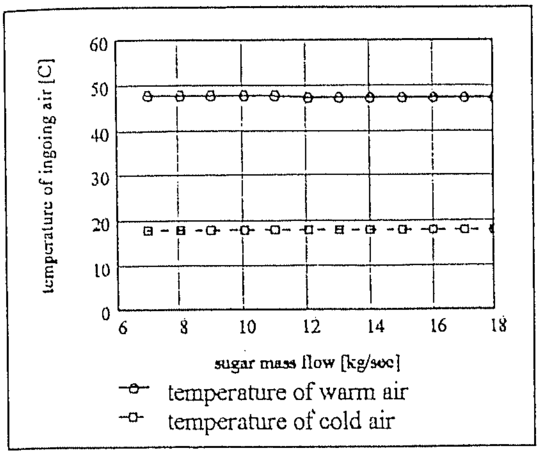

Fig.4.

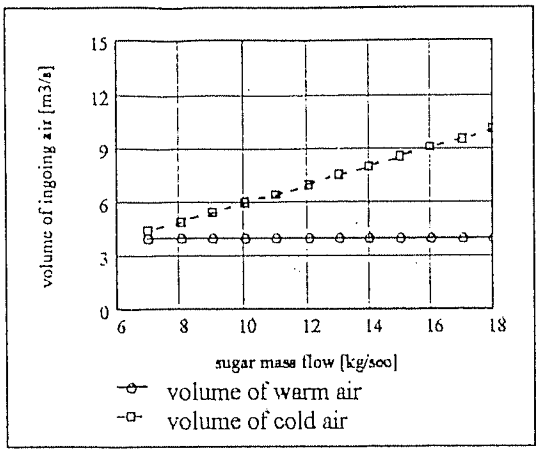

Fig.5.

According to the figures it is visible, that increasing the mass of the warm air every parts of the performance are increasing except the warm air heating, but the ratio of these parts are nearly the same. 60% part of the performance comes from the heating of warm air, 20% comes from the breathing ventilator, and 10-10% comes from the warm and cold air ventilators. Increasing volume of sugar the necessary drying air temperature is constant, while the volume of air is at the lower bound given by the ventilator. The necessary cold air volume is increasing with the volume of sugar. The conclusion is that from the point of view of drying the drying equipment has a reserve, the volume of the sugar can be increased.

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ACKNOWLEDGEMENT

This work has been supported by grant OTKA 22846 of the Hungarian Fund for Scientific Research.