Journal of Environmental Protection and Ecology 2, No 2, 516–522 (2001)

Clean technologies

NEW TECHNOLOGY FOR UTILIZATION OF THE WASTE HEAT OF FLUE GASES FROM DRYER INSTALLATIONS

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Abstract. The increasing of the energy efficiency is the best method for decreasing of green-house gases. The present work considers a possibility to decrease the fuel consumption of spray dryers for drying ceramic suspension for production of ceramic tile and, in the same time, utilization of the waste heat of flue gases for warming the plant. Based on preliminary studies, an industrial installation is constructed, and data from its testing are presented. It is shown that the re-circulation of the flue gases leads to about 15.6% reduction of fuel consumption. At the same time, in the cold season, the contact economizer system ensures about 1 MW heat, which is enough for warming the plant. The discussed ideas can be also used for energy efficiency increasing of other types of dryers.

Keywords: energy efficiency, drying, waste heat utilization, ceramic.

AIMS AND BACKGROUND

The modern spray dryers for ceramic suspension are cylindrical installations. The suspension, with concentration about 50%, is dispersed in them through many nozzles. The drying agent, a mixture of flue gases and air, with temperature 450-550°C, enters the upper part of the apparatus. The obtained dry product falls in the conic bottom of the apparatus and exits through a special device. The more fine dust separated in cyclones exits the installation by the same type of devices. The flue gases with temperature 100-115°C, containing about 22% vol. water vapour, exit the installation through a ventilator. To reduce their temperature, flue gases are diluted with air. The fuel is natural gas.

The problem for increasing of dryer energy efficiency is considered in case of the spray dryer in the plant "Khan Omurtag"– Shumen, Bulgaria. The experience shows[1-3] that among all kind of systems for flue heat utilization from wet gases, the best economical results are obtained using contact economizer systems. In this case, the gases are directly cooled in packed bed column (contact economizer) in counter current with circulated water flow. The utilized heat warms a pure circulating water flow in a heat exchanger. This type of installation is especially appropriate for high-humidity gases, because it makes possible to utilize very cheaply

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the heat of condensation of water vapour. Of course, the temperature level of the utilized heat is low because of low bulb temperature. At the above-mentioned case, the flue gases bulb temperature is about 63-64°C. When good contact economizer systems are used, the temperature of heated pure water is 58-59°C. A flow with such temperature can not be used for warming of plant halls, when the heating system is designed to operate with steam or with higher temperature water. It is possible to increase the temperature of the utilized heat by rising water vapour concentration in the flue gases after the dryer, which will increase the bulb temperature. It is easy to be done, if flue gases taken after the dryer are used instead of additional air. Naturally, to keep constant the drying process velocity and the humidity of the dried material in this case, the end temperature of the flue gases after the dryer must be higher.

EXPERIMENTAL

Preliminary estimation of the effect of flue gases re-circulation on fuel consumption for the drying process. The estimation of the effect of re-circulation on the energy efficiency can be done only using the process heat balance with and without re-circulation. In this case, physical or mathematical modelling is usually used. The exact physical modelling of such very complicated systems is practically impossible. The exact mathematical modelling requires knowledge of too much parameters, such as distribution of drop sizes, coefficients of heat and mass transfer in the gas phase, heat conductivity in the drops and its change with temperature and water contents, and others quantities, necessary for calculation of drying velocity. It is clear that a large information is necessary and its obtaining is difficult, slow, and expensive. On the other side, the construction of an industrial installation without warranty for its efficient operation is connected to a big economical risk. That's why, for solving the problem we accepted the following approach:

1. An initial, even if not very correct, estimation of the effect of degree of re-circulation on energy efficiency is made.

2. Construction of industrial re-circulation pipe and ventilator using this not very correct estimation.

3. Testing the energy efficiency of the installation.

Of course, in this case the initial estimation can be used if a very important condition is fulfilled, namely, the energy efficiency calculated on its base must be not lower than the real one with the given re-circulation.

Because the energy efficiency decreases with increasing of flue gases exit temperature, the selected method must ensure estimation of the value of this temperature equal or greater than the temperature, which will be obtained experimentally after re-constructing the installation. The estimation of exit flue gases temperature can be obtained as follows.

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The heat quantity Q, which must be transferred for drying of suspension drops, can be determined from:

$$dQ = K_t (t_G - t_S)\, dF, \qquad (1)$$

where K_t is the overall heat transfer coefficient, calculated taking into account the heat transfer from the flue gases to the drops surface, and also the heat transfer in the drops themselves, respectively in the solid phase; t_G – the bulk temperature of the gas flow, t_S – temperature of the drops, respectively of the dust; F – interfacial surface.

The rate of evaporation G is:

$$dG = K_G (P_S - P_G)\, dF, \qquad (2)$$

where K_G is the overall mass transfer coefficient, which takes into account both mass transfer in the drying material and in the gas phase diffusion boundary layer, P_S – the equilibrium partial pressure of the water vapours at temperature t_S, and P_G – its partial pressure in flue gases bulk.

Let we consider the end of the drying process, when the temperature t_G will be that of the leaving flue gases. The real flue gases temperature t_G will be between the temperature calculated in case of heat transfer limited drying process and in case of mass transfer limited one. If the process is heat transfer limited, the water vapours equilibrium partial pressure P_S will be equal to the partial pressure of the water vapour in the bulk gas flow P_G. At this assumption, t_S will be equal to the dew point.

If consider a process controlled by the mass transfer (with driving force $P_S - P_G$), the difference between the bulk temperature and that in drops centers will be zero , because at this condition the temperature difference does not influence the process velocity. Of course, in this case the outlet gas temperature will be quite lower and never will be higher than the water boiling temperature.

It is clear that the assumption for heat transfer limited process leads to obtaining of exit gas temperature not lower than the real temperature we want to obtain. In other words, if the increasing of energy efficiency by re-circulation is calculated using the above assumption, the calculated efficiency will be not lower than the really expected one. Because of the abrasive enlargement of nozzle sprayers, the dryer productivity increases with the time. To obtain the same humidity of the dried ceramic, the flue gases exit temperature must also increase with the time. Figure 1 presents the calculated outlet temperature of the flue gases versus gas humidity for different outlet gas temperature without re-circulation. The curves refer to heat transfer controlled drying process. For a given outlet gas temperature and humidity of flue gases without re-circulation, the temperature difference Δt is calculated by:

$$\Delta t = t_G - t_S \qquad (3)$$

The flue gases temperature with re-circulation is calculated assuming that t_s is the dew point and K_t, F, and Δt from equations (1) and (3) keep constant values independent from the re-circulation. This is not fully correct. Because of some possibility for capillary condensation, t_s can be higher than the dew point. K_t is also not exactly constant. It depends on the temperature and humidity and increases with increasing of each of them. A more exact estimation shows that the real temperature of exit flue gases can only be lower than this presented on Fig 1.

It means the expected energy efficiency can be only higher than calculated one using the values from Fig.1.

In all cases, the curves in Fig.1 are calculated for 22% flue gas humidity without re-circulation. This value is estimated experimentally for various conditions and is practically constant for all-important drying regimes.

The values of the heat $Q1$, necessary for evaporation of 1 kg water, from the ceramic suspension, calculated using balance equations is given in Fig. 2.

The calculations are done at the following presumptions:

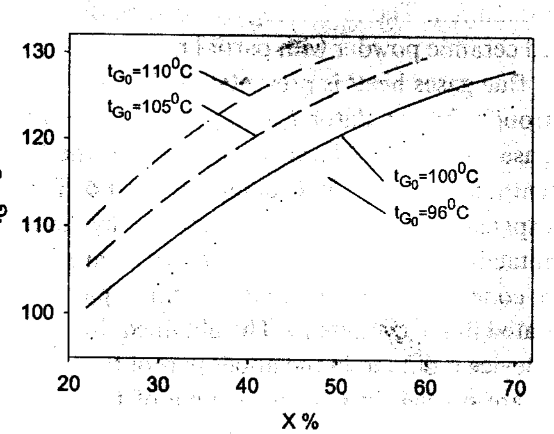

Fig. 1. Dependence of the calculated outlet temperature of the flue gases on the gas humiditi (X)

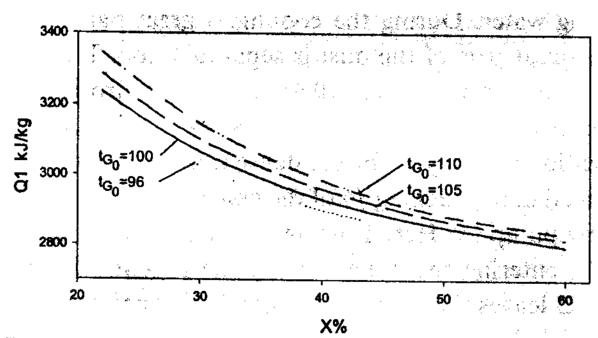

Fig. 2. A plot of $Q1$ versus gas humidity (X)

1. The flue gases exit temperature is determined from Fig. 1.

2. The fuel is pure CH_4. Its lower operating heat of burning is q= 35 880 kJ/nm³ (Ref. 3).

3. The humidity of the inlet air is equal to 0. More exact calculation shows that the error involved with this assumption is negligible.

The reduction of fuel consumption, defined with the ratio $Q1/Q1_0$, is given in Fig. 3. Here $Q1_0$ is the heat necessary for evaporation of 1 kg water from the ceramic suspension, calculated by balance equations without re-circulation. From Fig. 3 it can be seen that the reduction of fuel consumption increases with increasing of gas humidity, i.e. with the extent of re-circulation. For example, at

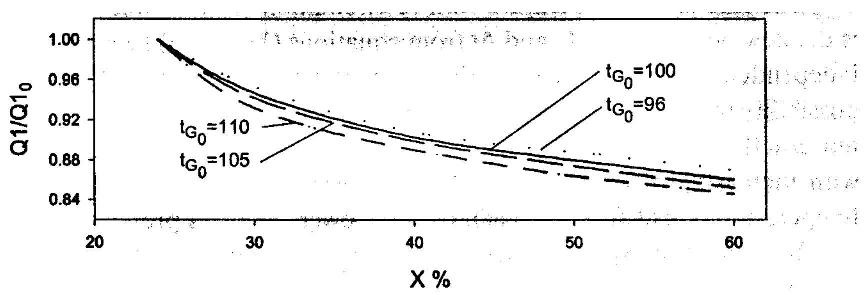

Fig. 3. Relationship between the reduction of fuel consumption and gas humidity

52% humidity, the reduction is between 0.86 and 0.884, depending on the flue gases exit temperature without re-circulation.

On the base of presented results, it was decided to reconstruct the dryer installation.

Technological scheme of the installation. The technological scheme of drying installation for production of dried ceramic powder with partial re-circulation of the flue gases and utilization of exit flue gases heat[4] is presented in Fig. 4. The installation operates as follows: air trough the ventilator *1*, natural gas as fuel through pipe *3*, and re-circulated flue gases by the ventilator *18* are fed into the burning chamber. The flue gases with temperature 450-550°C enter the dryer *6*. The pipeline *5* feeds there the ceramic suspension. The suspension is sprayed by the nozzles of the distributor *7* and dries contacting with the hot flue gases. In form of powder, the dried material settles in the cone bottom of the dryer. A small part of it, retained by the flue gases, is separated in the cyclone *10*. The obtained dried product leave the dryer trough a special device mounted in the upper part of the lines 8 and *9*. After the cyclone, flue gases are divided in two flows. One of them exits the installation through the ventilator *11* and the chimney. The other is fed in the burning chamber through the ventilator *18* and the duct *2*. At closed valve *12*, the flue gases enter through the duct *13* in the contact economizer *14*. Here it is scrubbed and cooled with cold circulating water. During the cooling, a great part of the water vapour condenses, and a great part of the dust is separated, too. The condense, containing the separated dust, exits the installation by the hydro-locking device *17* and can be used for preparation of the ceramic suspension before its drying. This will result in utilization not only of the condense water, but also of its heat. The circulated water warmed in the packing *16* of the contact economizer *14*, enters the heat exchanger *20* by pump *19*. Here it warms a pure water flow with initial temperature about 55°C, entering the apparatus by the pipeline *22*. The pure water heated to about 75 °C leaves the heat exchanger *20* through the pipeline *23*. The circulated water cooled in the heat exchanger *20*, enters the contact economizer by pipeline *21*, and by distributor *15* is spread equally over the cross

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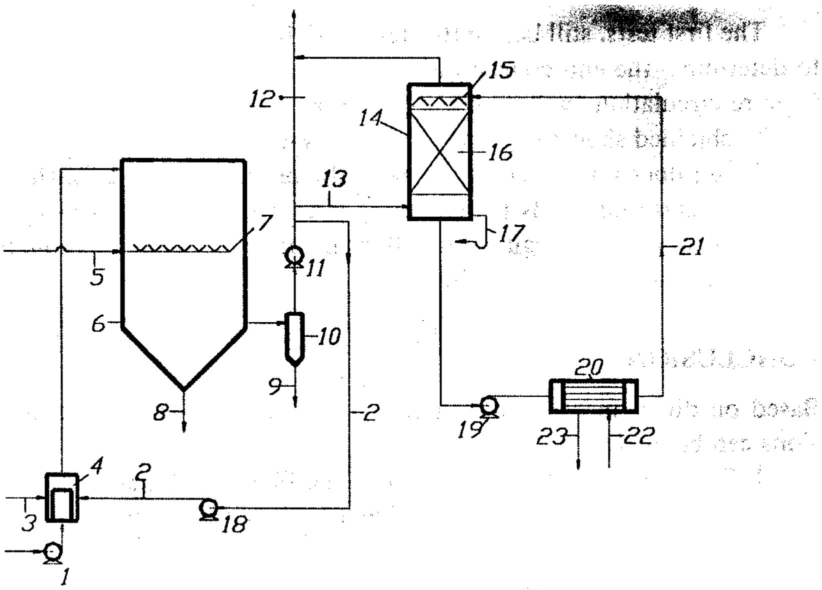

Fig. 4. Technological scheme of drying installation for production of dried ceramic powder

section of the economizer packing. The water warmed in the heat exchanger *20* is used for heating the plant. A part of it can be used also for bathrooms and for other purposes. The heat balance calculations show that operating at evaporation capacity of 2500 kg/h water (project capacity of the drier), the quantity of the utilized heat can reach 1.6 MW. Because of lack of heat consumers during the installation reconstruction, it was decided to design a contact economizer system for 1 MW. If needed, this system can be enlarged adding additional plates to the heat exchanger *20*.

RESULTS AND DISCUSSION

The results from the tests of the installation are presented in Table 1.

Table 1. Test data

Dimension	Without re-circulation	With re-circulation
Absolute pressure (kPa)	98.7	98.7
Productivity, dried material (t/h)	4	4
Initial flue gas temperature (°C)	513	482
Exit flue gas temperature (°C)	111	122
Exit flue gas bulb temperature (°C)	63.8	82.7
Exit flue gas humidity (vol. %)	22	52
Humidity of the dried ceramic material (%)	6	5.6
Reduction of fuel consumption due to re-circulation (%)	-	15.65

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The first tests, still before the design of the contact economizer system, aim to determine the end concentration of water vapour in the flue gases, at which their re-circulation will not significantly aggravate the burning process. The results obtained show that up to 52 vol. % water vapours in the flue gases, the re-circulation does not affect significantly the burning process. Further increase of their concentration leads to reduction of O_2 concentration, which is connected with difficulties in the regulation of burning process. For this reason, 52% humidity is chosen as "optimum" value.

CONCLUSIONS

Based on direct measurements and balance calculations, the following conclusions can be made:

1. The presence of ceramic dust in the flue gases does not clog the contact economizer system and does not influence its normal operation.
2. The increasing of flue gases humidity to 52%, because of re-circulation, leads to 15.65% reduction of fuel consumption for the drying process without increasing the humidity of the dried product.
3. The new contact economizer system utilizes up to 1MW heat.
4. The reduction of fuel consumption, both for drying and for warming the plant, is up to 43 %. The reduction of CO_2 emission is the same.
5. The quantity of the exhausted flue gases is reduced about 3.5 times. At least the same is the reduction of ceramic dust emissions. The real decrease of the dust emission is larger because of scrubbing the flue gases in the contact economizer.

The comparison of the experimental data for the exit flue gas temperature and for the increasing of the dryer's energy efficiency with the data given in Figs 1 and 3 shows that the real temperature is about 10°C lower, and the efficiency is about 2% higher than the predicted values. The reason is, as it was mentioned before, that the calculations of the curves in Figs 1 and 3 were made assuming heat transfer limited process, which leads to obtaining of higher exit flue gas temperature and lower energy efficiency than the real ones.

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Received 24 November 2000
Revised 28 April 2001