SEWAGE SLUDGE THERMAL DRYING AND HYGIENIZATION IN A CLOSED LOOP ENERGY RECOVERING SYSTEM

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Abstract: Thermal drying and hygienization of sludge significantly enhances the number of possibilities of its further usage; not only as a fuel but also for environmental purposes. Proposed in the paper sewage sludge drying and hygienization system with a heat pump is an alternative for the traditional method of sludge drying. Heat pump drying system is energy efficient and avoids emissions from the drying installation. In that system sludge is dried by a closed loop circulating air treated in the heat pump. The refrigeration capacity of the heat pump is used to dehumidify moistened air while the heating capacity is used to reheat the cooled dry air.

In the considered heat pump system carbon dioxide (CO_2) was applied as a refrigerant. Carbon dioxide as a natural working fluid in heat pump systems is increasingly important in view of the HFC (Hydrofluorocarbons) alternatives. Due to the critical parameters of CO_2 (t_c = 31,1 ^oC and p_c = 73,8 bar) the process in the CO_2 heat pump is the transcritical cycle. It provides the possibility of an additional hygienization of the dried product which becomes sanitarily safe and environmentally sound.

The article presents some of the measured characteristics of sludge drying along with the conception of applying CO_2 heat pump for sludge drying with energy recovery and sludge hygienization.

1. INTRODUCTION

The raw sludge, coming from wastewater treatment processes, is highly hydrated (up to 99%) [1, 5] therefore its further utilization in most cases is possible only after sludge dewatering and drying. Thermal drying is the last stage of removing water from sewage sludge, after thickening and dewatering. It requires the highest energy supply, but provides the best results (Fig. 1). Thermal drying of sludge significantly enhances the number of possibilities of its further usage; not only as a fuel but also for environmental purposes.

The traditional methods of sludge drying are based on the process of evaporation of water in the temperature of minimum 100 ^oC. Consequently the drying process requires a lot of energy and therefore is very expensive with high environmental impact. The considered in the paper heat pump drying system for sewage sludge is an alternative for the traditional method of sludge drying.

Heat pump recovers low temperature heat (e.g. the heat of the sewage in the sewage treatment plant) to produce a high temperature heat. It usually consists of four main elements: (1) evaporator, (2) compressor, (3) condenser and (4) expansion valve (Fig. 2). The working fluid (refrigerant) changes from liquid to gas (evaporates) as heat is absorbed from the heat source. Than it undertake a refrigeration circuit, first it goes to the compressor, later to the condenser, where the working fluid condenses to liquid (or is cooled down if a cycle is transcritical) as heat is released, and finally to the expansion valve. Heat released in condenser (or gas cooler in transcritical cycle) is the effect of the heat pump work and may be used for different purposes. Heat pump needs some energy to work. Usually an electric motor is used to supply power to drive the compressor.

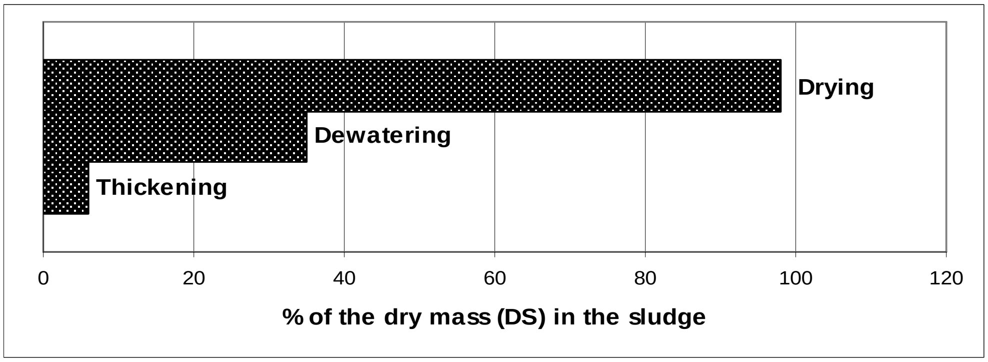


Figure 1. Concentration of dry mass (DS) in the sludge after processes of thickening, dewatering and drying [1, 2, 6].

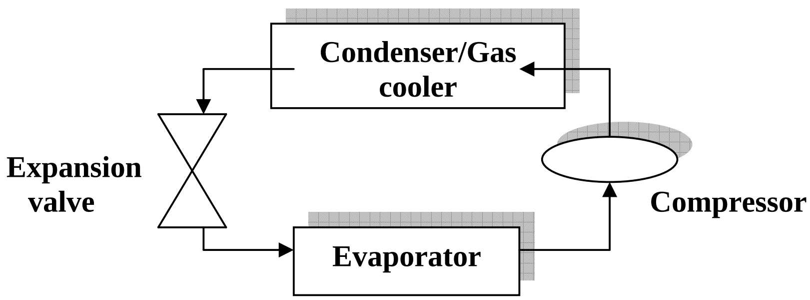


Figure 2. Schematic view of the heat pump.

Heat pump drying system for sludge is energy efficient and avoids emissions from the drying installation. If CO_2 is applied as a refrigerant in the heat pump the installation gives also the possibility of hygienization of the dried product, which is especially important if the sludge is to be used environmentally. In addition, carbon dioxide, a natural working fluid, diminishes the influence of the installation for sludge drying on the Global Warming Effect.

2. CONCEPTION OF THE HEAT PUMP SLUDGE DRYING SYSTEM

Energy savings in the installation for sludge drying with the heat pump results from the possibility of highly efficient energy recuperation in the heat pump cycle and from realization of the drying process in a closed loop air of controlled temperature and humidity. In that system sludge is dried by a closed loop circulating air treated in the heat pump. The refrigeration capacity of the heat pump is used to dehumidify moistened air (in the evaporator) while the heating capacity is used to reheat the cooled dry air (in the gas cooler) which returns to the drying chamber (Fig. 3). Additionally, a part of heat at higher temperature is used in the hygienization chamber, which is especially important in context of the environmental utilization of dried sludge. The drying air circulates in a closed loop what makes realization of the process independent from the atmospheric conditions, what enables recuperation and hermetization of the process.

Applying carbon dioxide (CO_2) as a working fluid in the heat pump drying system causes that the thermodynamic processes will be realized according to the transcritical cycle. It means that the working parameters of the CO_2 will cross the critical point, which for CO_2 is defined as: $t_c = 31{,}1\ ^oC$ i $p_c = 73{,}8$ bar. In the lower part of the cycle (connected with evaporation of the refrigerant) the parameters of the working gas will be beneath the critical parameters and in the upper part of the cycle (connected with gas cooling) the parameters of the working gas will be higher than the critical parameters of CO_2.

The transcritical cycle results in high compressor discharge temperature. High refrigerant temperature at the gas cooler inlet represents an advantage in a sludge dryer as it provides additional hygienization of the dried product which becomes sanitarily safe and environmentally sound.

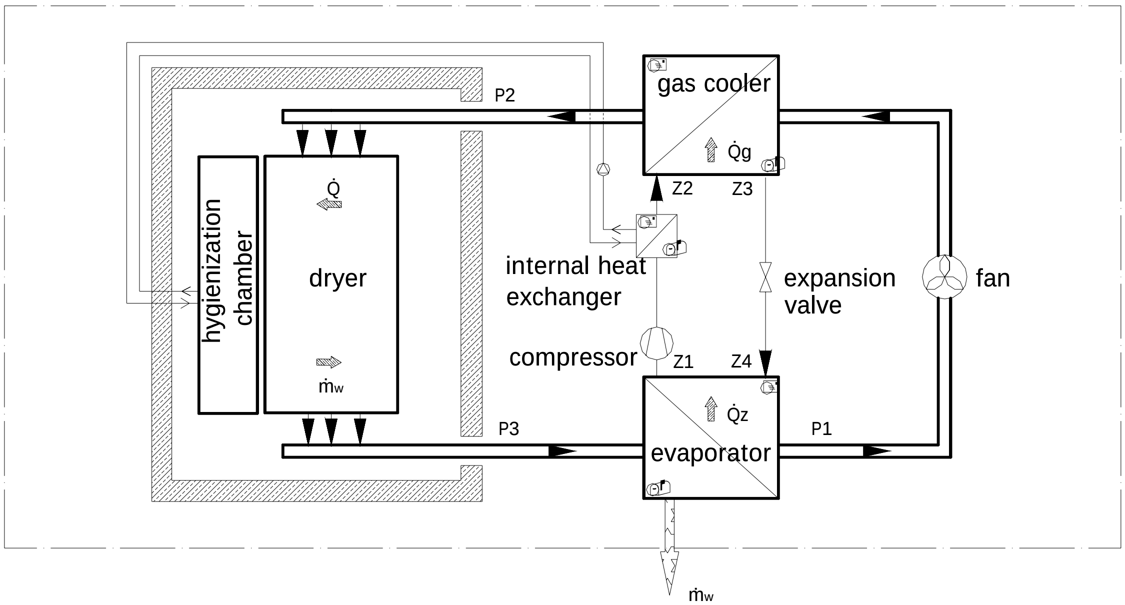


Figure 3. Conception of the heat pump sludge drying system [3].

Applying carbon dioxide as a refrigerant in a heat pump drying system for sludge drying not only enables hygienization of the dried sludge, but is also increasingly important in view of the HFC (Hydrofluorocarbons) alternatives. The regulations of the new 70/156/EEC Directive, concerning the use of refrigerants with GWP (Global Warming Potential) higher than 150, force engineers to look for the new kind of refrigerants. Carbon dioxide (GWP = 1), naturally present in the environment, is seen as a promising alternative to refrigerants with high GWP, usually coming from HFC group.

3. ENERGY EFFICIENCY OF THE CO_2 HEAT PUMP FOR SLUDGE DRYING

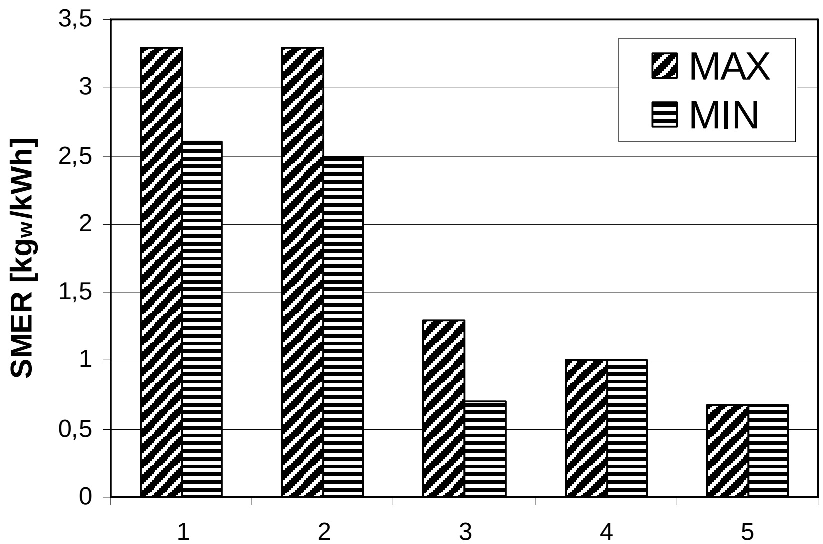
To compare different technologies of drying, in respect of energy demand, Specific Moisture Extraction Rate (SMER) should be calculated for each method. SMER [kg_w/kWh] is an indicator which shows the rate of moisture removed from the dried material per 1 kW of energy input to the cycle [7].

$$SMER = \frac{m_w}{E}$$

Where:

m_w - mass of moisture removed from the dried material [kg_w];
E - energy input to the cycle [kWh]

To calculate SMER for CO_2 heat pump dryer CYCLE-11UA-CO_2 program has been applied. The initial calculations showed that the considered technology is several times more energy effective than most of the applied technologies for sludge drying (Fig. 4). Comparable values of SMER indicator were achieved only for Watromat technology [4], which is also based on the heat pump. However, in the heat pump from Watromat technology freon R404a is used as a working fluid. Global Warming Potential (GWP) for this refrigerant is 3750 what 25 times exceeds the recommended maximum. Therefore it is not an acceptable solution for sludge drying in reference to the regulations of the new 70/156/EEC Directive. In addition, what is the next advantage of CO_2 heat pump dryer, Watromat technology does not provide hygienization of the dried sludge.



Drying technology: 1- CO_2 Heat pump drying; 2- Watromat technology; 3- Gas technology (direct drying); 4- Oil technology (indirect drying); 5- Steam technology

Figure 4. Comparison of SMER indicators for different technologies of sludge drying [3].

4. SLUDGE DRYING LABORATORY TESTS

There is a need for laboratory tests of sludge drying process. Information gathered from such tests will help to choose the optimal technology of sludge drying and to describe sludge as a material which is being dried. For now there is no sufficient source of information which could help with that problem. All the literature concerning sludge issue is focused mostly on the processes during which sludge is being produced, on the processes of sludge thickening and dewatering and also on different methods of sludge utilization. There is an undeniable need for more information as far as sludge drying is being concerned.

To fulfill the expectations in that field the laboratory for sludge drying tests has been performed. In the specially build computerized laboratory stand samples of sludge can be dried at controlled temperature and relative humidity. For now the first test series have been conducted. The results are presented in Fig. 5 and Fig. 6. Sludge sample was dried by the air of 63 degrees Celcius. After 22 hours, during which the sample reached the stabilized state with the surrounding environment, the temperature of the process air was changed to 72 degrees Celcius. It hasn't influenced the mass of the sludge sample and proved that sludge has been already dried. On the basis of the mass of sludge sample obtained in the end of the test the concentration of Dry Mass (DS) in sludge during the whole process of drying was calculated. (Fig. 6) The results of the calculation showed that the initial concentration of DS in sludge taken to dry was approximately 85%. The mass of water removed during drying was approximately 109g. The mass of the sludge sample changed from approximately 129g to 20g.

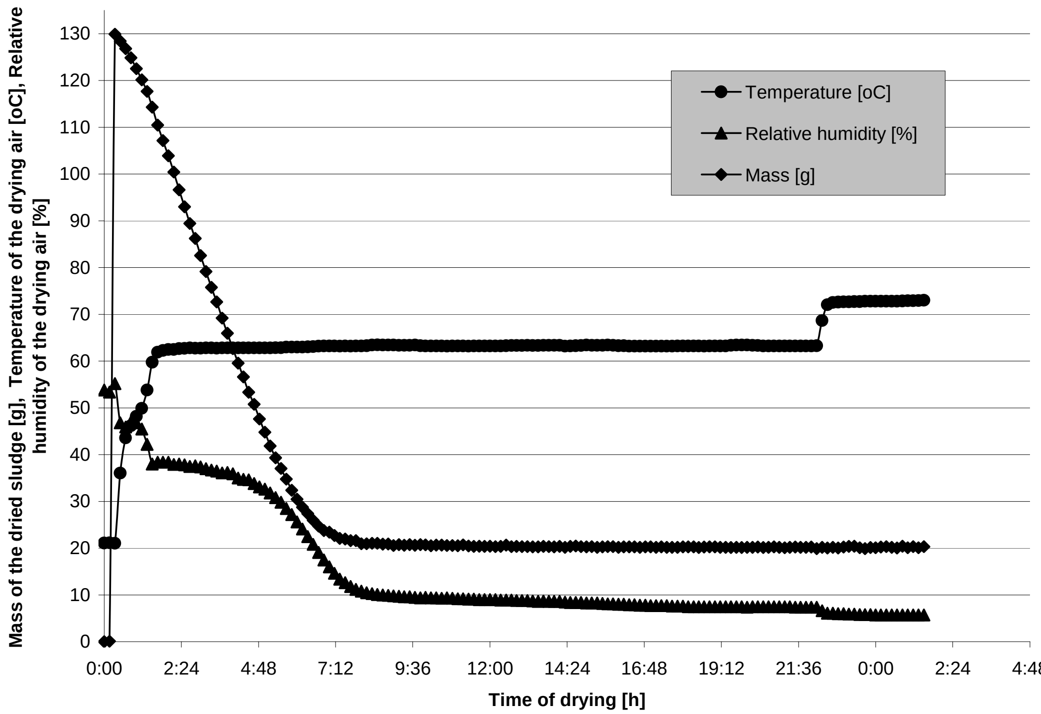


Figure 5. The results of sludge drying test.

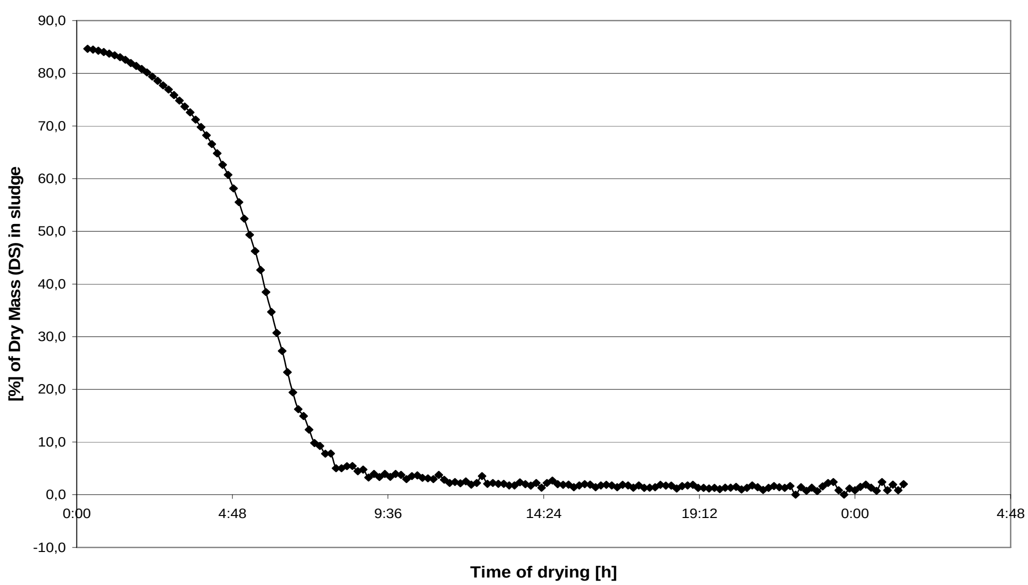


Figure 6. The concentration of Dry Mass (DM) in sludge during the process of drying.

The laboratory still needs some elements to be complete. At the moment the system for humidity control is being installed. The next step will be the measurement and data acquisition system setup.

5. SUMMARY

CO_2 heat pump dryer for sewage sludge drying is an energy efficient and environmentally less harmful alternative to the traditional method of sludge drying. It also provides additional hygienization of the dried product which becomes sanitarily safe and environmentally sound. Applying naturally present in the environment CO_2 as a refrigerant in the heat pump cycle is consistent with the regulations of the new 70/156/EEC Directive which excludes the use of refrigerants with GWP higher than 150.

There is a need for the laboratory tests of sludge drying process which will help to choose the optimal technology of sludge drying and to describe sludge as a material which is being dried.

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