Medium-Temperature Belt Dryers for Biosolids

Markus Roediger

Dr. Roediger Consult, Stuttgart, Germany (dr.m.roediger@t-online.de)

ABSTRACT

Drying saves biosolids transportation and disposal costs. A brief historical review about thermal biosolids drying technologies is provided. Main technical features of belt dryers are explained in comparison with drum, fluidized bed, contact and solar dryers. While most belt dryers were originally designed for low-temperature operation, medium or high temperature designs have now become more common. Advantages of higher temperature operation are smaller dryers, reduced exhaust air flows and improved odor control. Medium-temperature dryers can achieve disinfection and thus generate Class A biosolids, even if they are entirely operated with medium-temperature heat of around 85 °C (185 °F) from CHP (Combined Heat and Power) systems. The time-temperature regime according to US-EPA Biosolids Rule 503 in belt dryers is explained. Results from the measurement of air and solids temperatures within a medium-temperature belt dryer are presented. Use of waste heat for sludge drying provides great economical and ecological advantages in comparison to direct use of fossil energy, such as natural gas.
A list of some reference installations by several suppliers includes key technical data.

KEYWORDS: Biosolids, Sludge Drying, Medium-Temperature Belt Dryer, Biosolids Disinfection, Class A Biosolids, Heat Supply from CHP Systems

INTRODUCTION

Biosolids disposal is becoming ever more difficult and expensive as fuel and transportation costs are rising. Landfilling of biosolids is no longer permitted in Europe, due to unavoidable methane and carbon dioxide emissions and to avoid burdening coming generations with long-term care. It is only a question of time, when landfilling of biosolids will also be abandoned in America.

Biosolids can be incinerated and the remaining ash may be disposed on landfills. Nutrients are lost. Global P resources of sufficient quality for use as fertilizer are limited. Presently recovery of P from ashes is far from economical. Ash from biosolids incineration could be stored in dedicated landfills, permitting future P recovery. Direct land application of phosphorus-rich ash is usually prevented by its content of heavy metals. Incineration of dewatered biosolids consumes energy for water evaporation. Anyway, hauling wet biosolids to far away incineration sites, e.g. power plants, consumes fuel and is becoming ever more expensive.

The preferred option for beneficial biosolids reuse, i.e. direct land application, is under continuous threat. In some European countries, such as the Netherlands and in Scandinavia, pollutant limits are so low that land application has become virtually impossible. Even where land application remains long-term feasible, hauling distances and costs are continuously rising. Beneficial use of disinfected Class A biosolids is preferred in America.

Whatever the remaining and preferred biosolids reuse or disposal options are, long distance hauling of dewatered biosolids still containing 75 % to 85 % of water makes little economical sense. If dewatered biosolids are dried from e.g. 25 %DS to 90 %DS, their mass is reduced to about 28 %. Dried biosolids have a caloric value similar to that of brown coal and can be used as carbon-dioxide-neutral and renewable fuel for power and heat production.

Sludge dryers have been increasingly installed in Europe and, more recently, also in America and developing countries, even in China. Sludge drying reduces transportation costs and facilitates incineration in power plants or cement kilns.

BRIEF HISTORICAL OVERVIEW OF THERMAL BIOSOLIDS DRYING

Some thermal biosolids dryers were installed in Europe during the 1970s and 1980s. Convective drum dryers or contact dryers were commonly used. Several dryers caught fire. High dust generation, in combination with high temperature, require sophisticated safety means to prevent dust incineration or even explosion. The main disadvantage of such high-temperature dryers became their increasingly expensive fuel consumption, unless they were installed at a site where high-temperature waste heat was available, e.g. next to power stations or cement kilns. But these are not commonly located near wastewater treatment plants, resulting in the need for expensive hauling of wet sludge.

Belt dryers have been increasingly used for biosolids drying since the 1990s. They generate little dust because the biosolids are gently conveyed on belts through the dryer. Belt dryers are operated at low or moderate temperature. The risk of dust incineration is low, operation is safe and easy. Their design is simple and little maintenance is needed.

Initially, belt dryers were designed for low-temperature operation (below 50 °C or 122 °F) and were operated with a large flow of ambient air that was unheated or only moderately warmed up. Low-temperature dryers have the advantage of simplicity, but they are large. They require large air flows and much power for blower operation. At some sites, in spite of the low drying temperature, the exhaust air was significantly more odorous than previously anticipated, requiring later addition of expensive deodorization systems for their large exhaust air flows.

Belt dryers are now increasingly designed for medium-temperature operation with air temperatures between 80 and 130 °C (175 – 265 °F). In comparison with low-temperature belt dryers, they have the following advantages: they are more compact; most of the dryer air is recirculated through the dryer; exhaust air flow is smaller and thus easier to deodorize; they can disinfect biosolids to generate a Class A product. To keep fuel consumption low, medium-temperature belt dryers should be preferably installed where waste heat of sufficient quantity and temperature is available, e.g. from CHP systems.

Solar dryers were developed in Germany, which is rather ironic, since this is a country with low sun radiation intensity and poor climatic conditions. Solar dryers require large footprint and long detention time. For this reason additional heat is sometimes provided, e.g. by heat pumps extracting heat from plant effluents. Solar dryers are preferably installed in arid climate and at small treatment plants. The biosolids within the dryer must be turned over many times by mechanical means. To avoid excessive dust generation and product disintegration, newer systems are designed to achieve only about 70 %DS. A shortcoming of solar dryers is that they cannot reliably generate Class A biosolids in moderate climate, unless they are provided with a prior or subsequent disinfection process.

MEDIUM-TEMPERATURE BELT DRYERS

Belt dryers are relatively compact. A couple of open-porous belts are stacked above each other within a thermally insulated enclosure (See Fig. 2). Dewatered biosolids are placed on the upper belt as an even and porous layer with a large specific surface. Such a layer is formed e.g. by extrusion of spaghetti-shaped strings through a perforated matrix (See Fig. 1). Another option is formation of sludge particles in a pug mill, whereby dried sludge is usually recirculated. The biosolids layer is slowly moved on the upper belt and slides at its end over a chute onto the lower belt. Dust generation is small because the biosolids are not subject to abrasive mechanical stress or shear.

Blowers draw hot air through the belts and the sludge layers thereon, in an upward or downward direction (See Fig. 2 to 5). The hot air heats the biosolids and evaporates water. During their slow movement through the dryer, biosolids become continuously hotter and dryer. They are dried to between 65 and over 90 %, depending on detention time and drying temperature.

Figure 1: Extrusion of spaghetti-shaped strings onto the upper belt (HUBER)

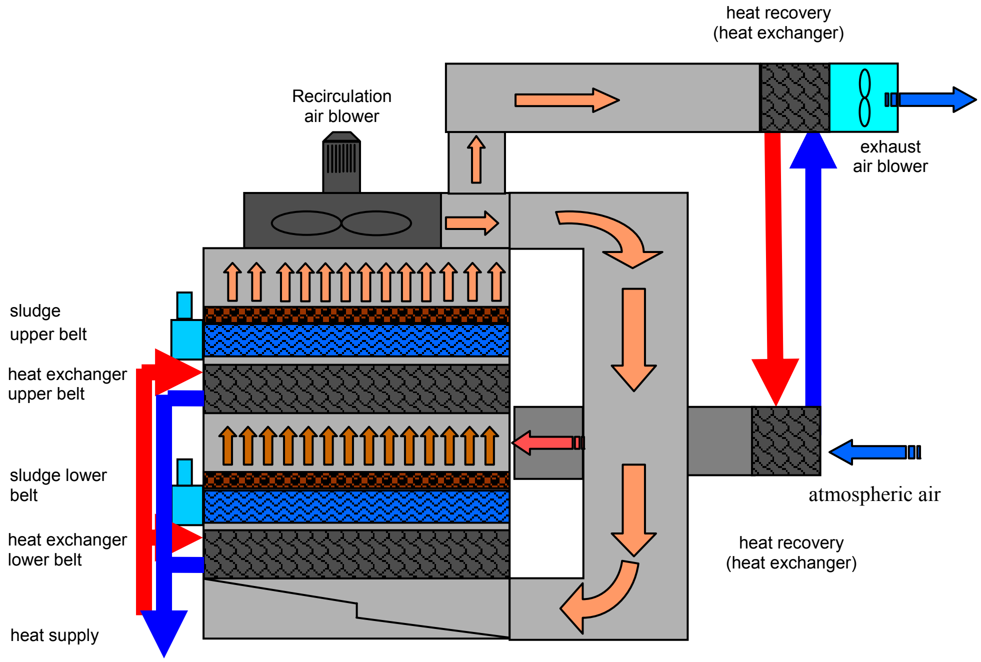

Figure 2: Low- or medium-temperature belt dryer (HUBER)

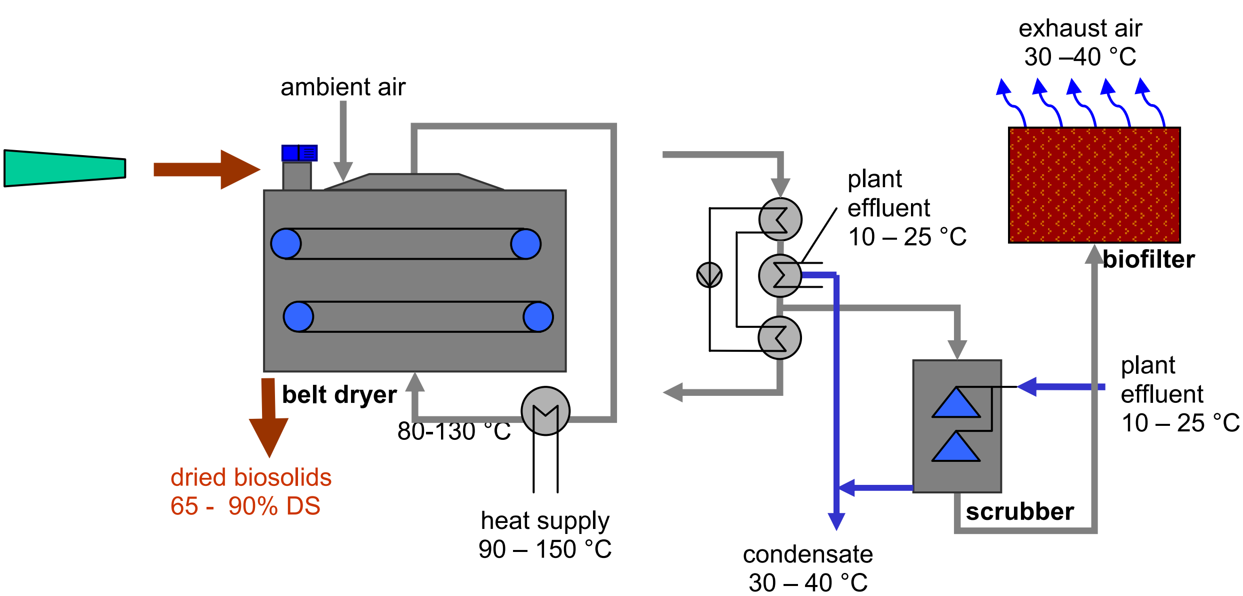

Figure 3: Medium-temperature belt dryer with two belts, upward flow, condenser, scrubber and biofilter (HUBER)

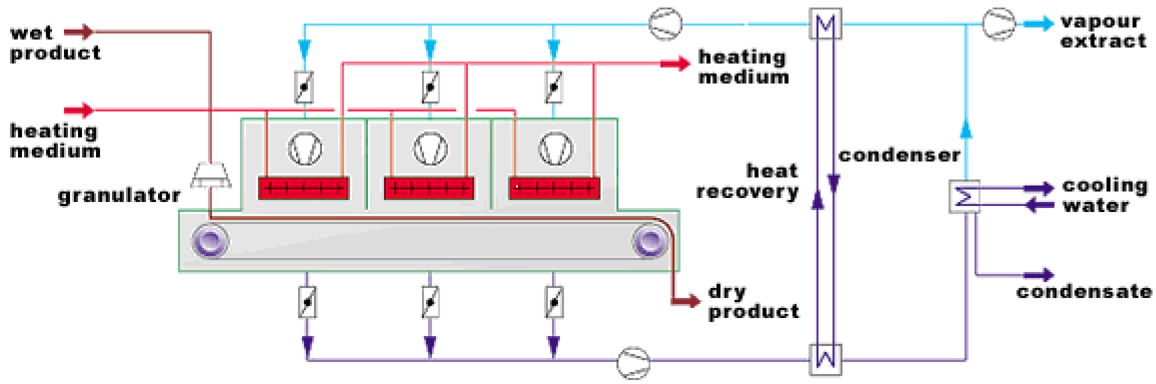

Figure 4: Medium-temperature belt dryer with single belt, downward flow and condenser (SEVAR)

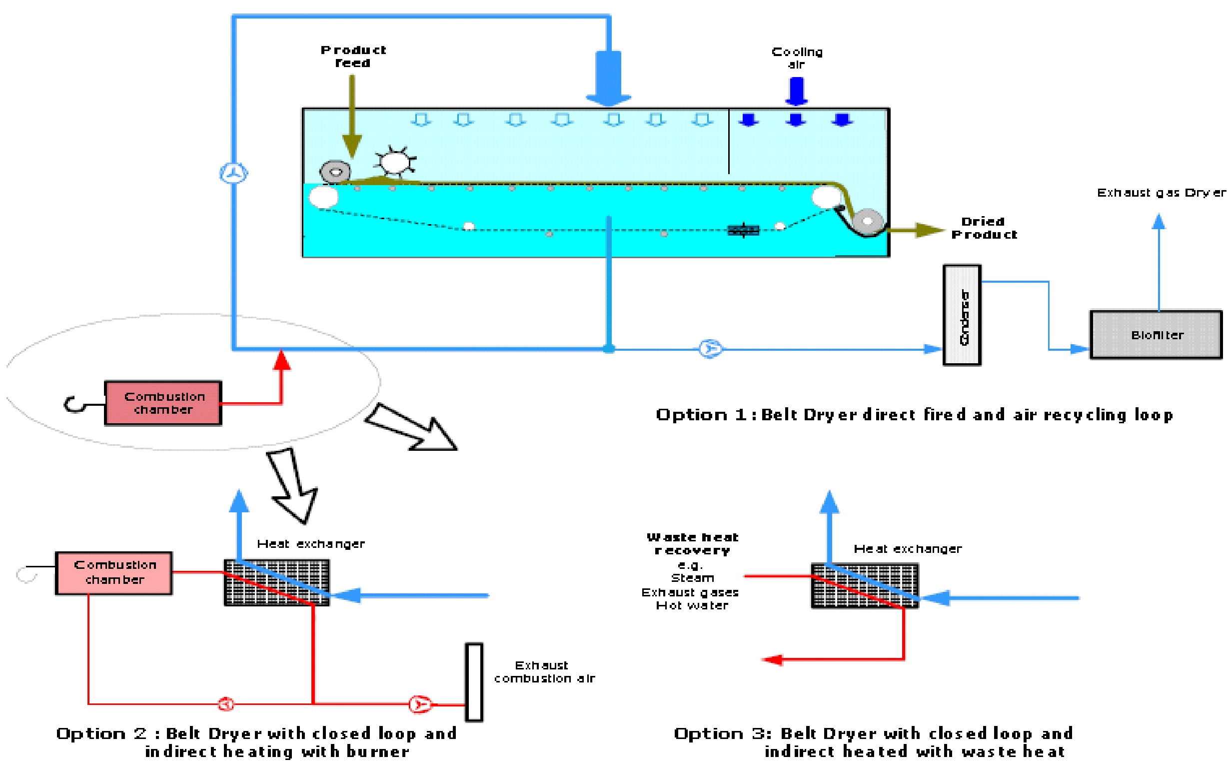

Figure 5: Direct or indirect heating options (ANDRITZ)

The humidity of the air increases when it is drawn through the biosolids and its temperature drops. Recirculated air can be dehumidified in a condenser (See Fig. 3 and 4) wherein humid air is cooled, e.g. with plant effluent, below its dew point, so that water is released as condensate. Removed heat is recovered through heat exchangers.

Recirculated air is reheated via heat exchangers. Alternatively, it can be heated with an in-line gas burner, or hot gases (e.g. flue gas) can be recirculated through the dryer (See Fig. 5).

Another blower draws a comparatively small exhaust flow out of the recirculation loop. This withdrawal of air keeps the entire dryer at a small under-pressure, thus preventing escape of air, odor and vapour through leaks. The exhaust flow is cooled, e.g. in a scrubber, to a temperature below 40 °C (105 F) and then blown through a biofilter for deodorization. An equal flow of atmospheric air enters the dryer. This air is pre-heated with heat recovered from the exhaust air.

Temperatures and the CO-concentration within the dryer air are monitored. A sprinkler system can be provided for fast cooling and combustion extinguishing after an emergency shut-down.

OTHER TYPES OF BIOSOLIDS DRYERS

Drum Dryers

Drum dryers are operated at minimum 400 °C (750 °F). They are directly heated with fossil fuel (See Fig. 6 and 7). Use of low or medium-temperature waste heat is limited to pre-heating of the incoming air. Drum dryers reliably generate disinfected Class A biosolids due to their high operation temperature.

Some dried product is returned and blended with the wet biosolids to generate particles of a certain size. Considerable amounts of dust are generated within the dryer. The dried product is screened: dust and undersized particles are recirculated, oversized particles are crushed and then also recirculated, only medium-sized particles with a diameter between 2 and 4 mm (0.08 to 0.16 inch) are removed as final product (See Fig. 6).

Recent testing by Bullard et al. (2008) of a drum drying system installed at the township of Cary, NC showed that the final product leaving the product cooler contained only 0.3 % (by mass) dust (particle size < 0.5 mm), but far more dust was generated during product conveying and storage, so that the final product leaving the silos contained about 4 % dust. Not only product cooling, but also temperature monitoring and purging of product silos with inert nitrogen gas are provided for operational safety. The product handling equipment is structurally designed to be explosion-proof. The exhaust is led through a dust filter and further treated with a venturi-scrubber. Ventilation of the silo and truck loading station are also provided with a dust filter.

All performance and emission requirements at the drum dryer plant of Cary were met or exceeded during the testing period. Thermal energy consumption of the drum dryer was below 0.8 kWh per kg of water evaporated. This is a good efficiency, but the required heat is entirely generated from fossil fuel.

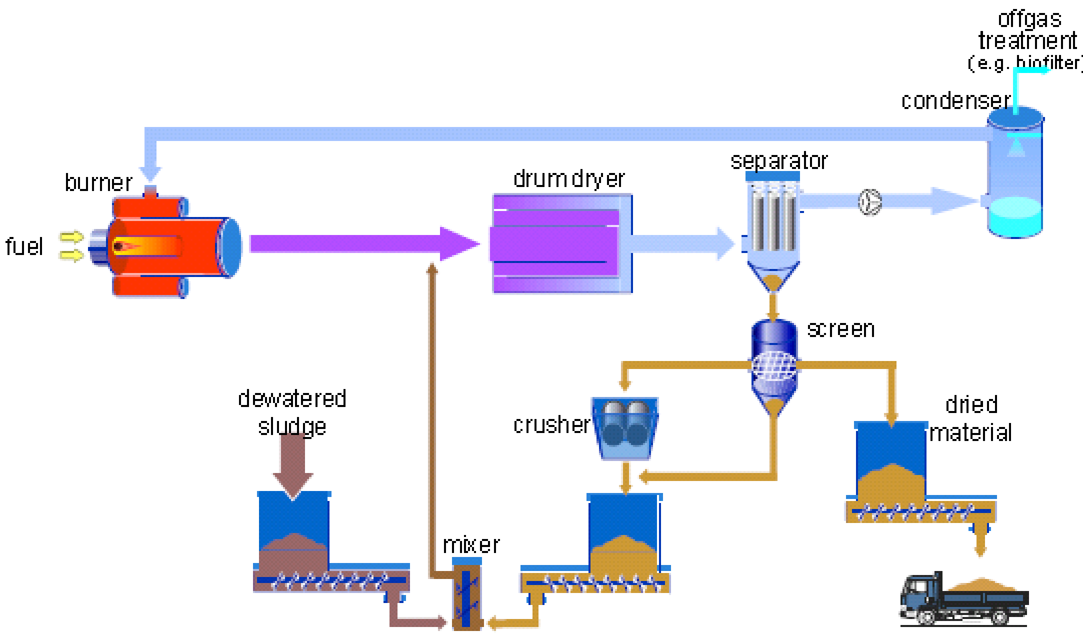

Figure 6: Directly heated drum dryer (ANDRITZ)

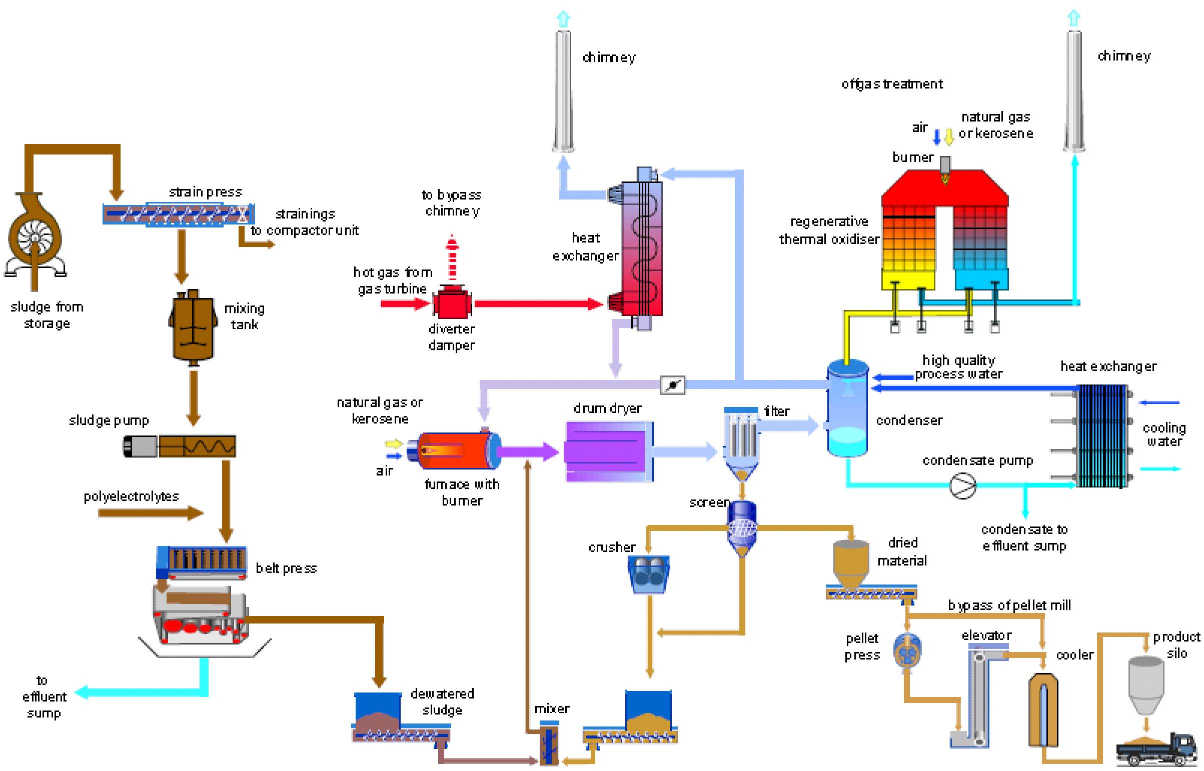

Figure 7: A complex drum dryer system in the UK (ANDRITZ)

Drum dryers are a good option for large plants. They produce a dried product of excellent quality. The dryers are compact, but the ancillary equipment is rather complex (See Fig. 5) and they require sophisticated safety provisions. They are operated at high temperature, consume fossil fuel and can not be operated with medium-temperature waste heat from CHP systems.

Fluidized Bed Dryers

Like drum dryers, fluidized bed dryers require recirculation of dried product. Fluidized bed dryers are always indirect dryers, the heat is supplied at high temperature in form of thermo-oil or steam (See Fig. 8). They are operated with fossil fuel and can not use medium-temperature waste heat from CHP systems.

The solids detention time in a continuously fed fluidized bed is not well defined: short-circuiting through the dryer is possible, so that Class A generation remains questionable. High shear forces in fluidized beds result in substantial dust generation.

Due to their compactness, fluidized bed dryers are an interesting option for large plants.

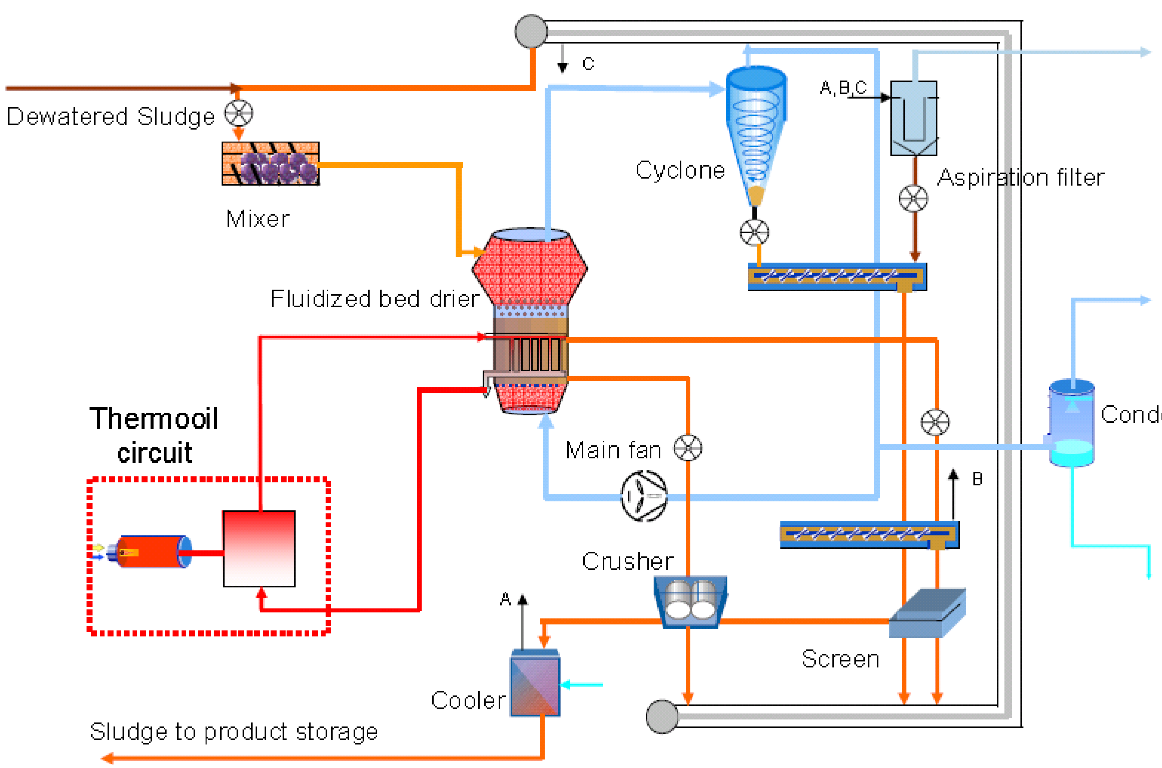

Figure 8: Fluidized bed dryer (ANDRITZ)

Contact Dryers

Contact driers are also heated with thermo-oil or steam (See Fig. 9). The heating medium is kept separate from the biosolids, heat is transferred through metal plates. To prevent caking, the solids must be continuously scraped from the contact surfaces by mechanical means. The particle size of the dried product is in a wide range and the dried product contains much dust. Contact driers can produce Class A biosolids.

Contact dryers need fossil fuel or high-temperature heat and can not be operated with medium-temperature heat from CHP systems.

During the 1980s and 90s a considerable number of contact driers were installed in Europe by several suppliers, but few systems are still in service. A number of contact driers were installed in America until a contact dryer caught fire in Ocala, FL (Water Industry News 2004).

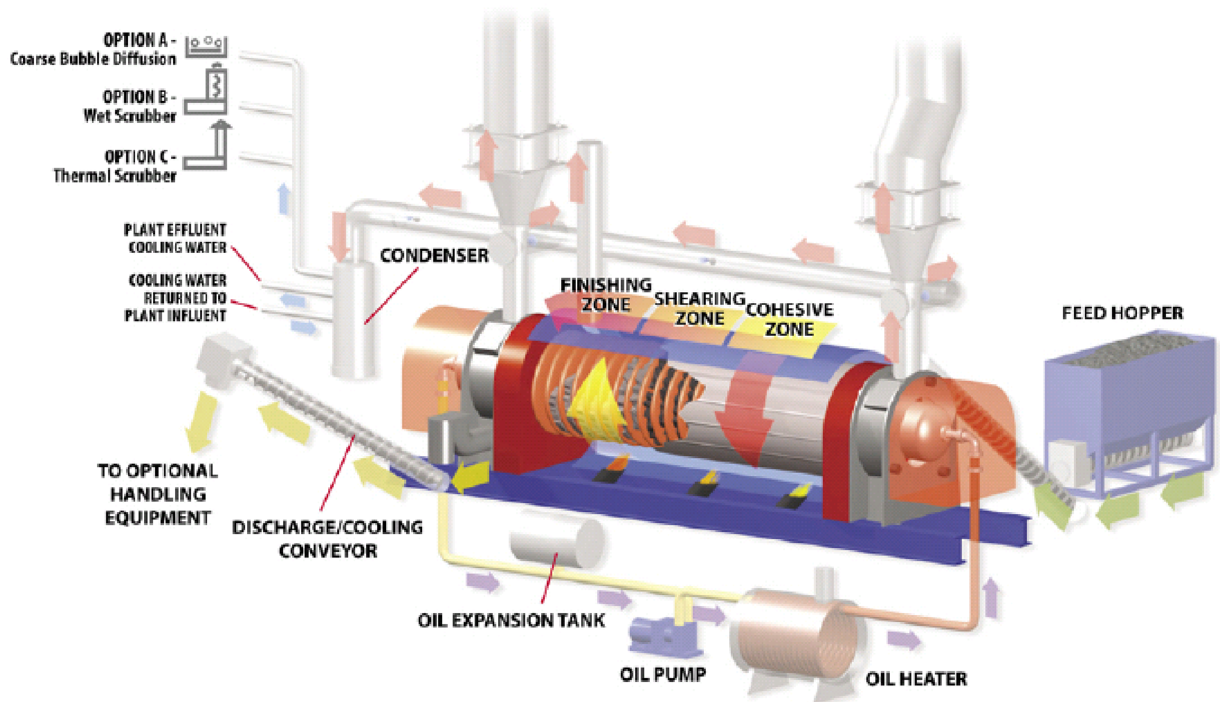

Figure 9: Contact Dryer (US-FILTER / SIEMENS)

Solar Dryers

Dewatered biosolids are spread on a large floor that is housed in a greenhouse. Sludge layers with a height of 100 to 250 mm (4 to 10 inch) are turned over by mechanical means to provide sufficient contact between wet biosolids and warm air. One supplier provides a batch system with a remotely controlled small vehicle, a so-called “mole” or “pig” roaming through the entire greenhouse area (See Fig. 10). Other suppliers use travelling product turners. One supplier’s

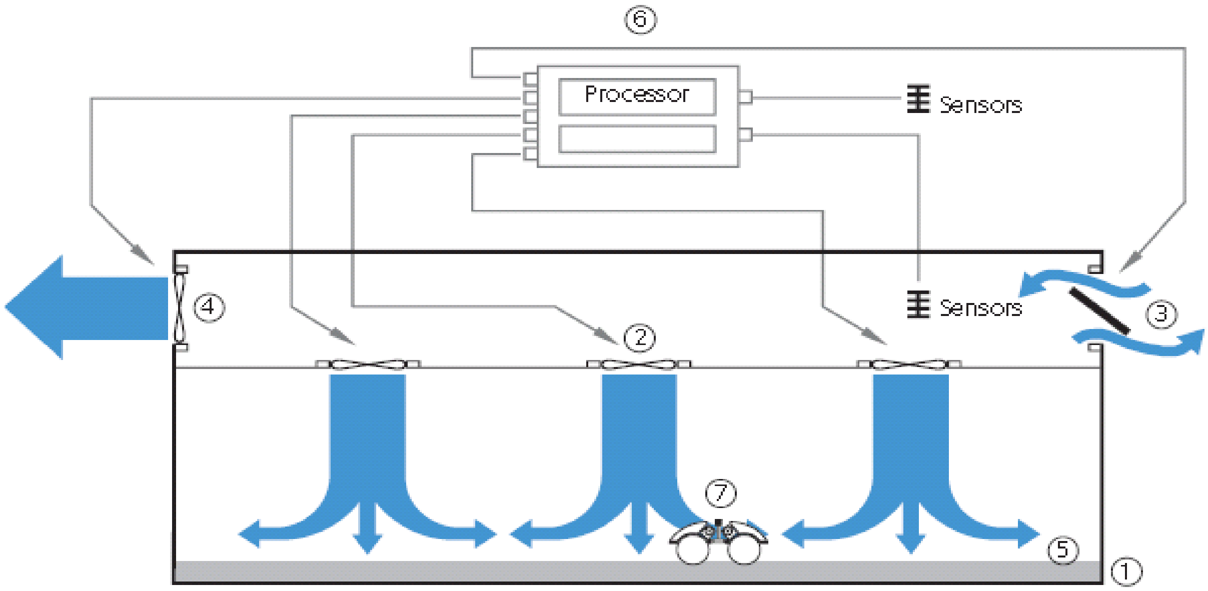

Figure 10: Solar dryer with remote-controlled vehicle for sludge turning (THERMO-SYSTEM)

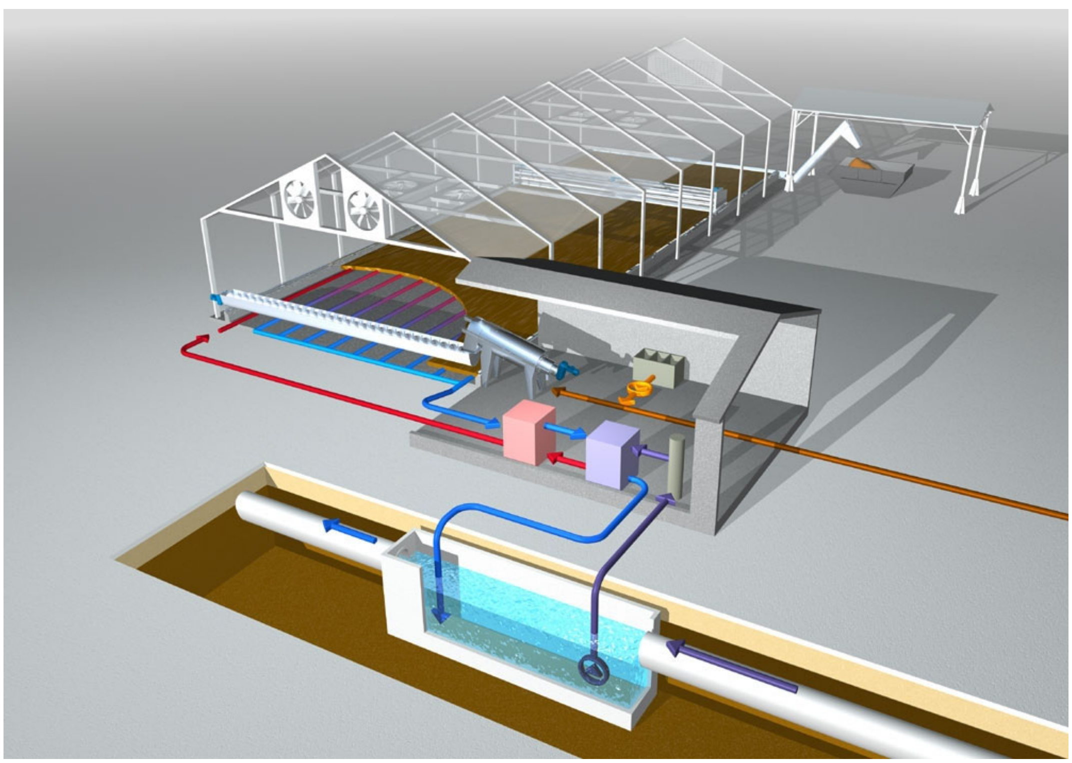

Figure 11: Solar dryer with additional heat pump for floor heating and travelling product turner (HUBER)

sludge turner can also be used to return dried sludge from the discharge end in order to generate granular and open-porous sludge at the feed end (See Fig. 11). The required footprint is large, depending on solar radiation intensity as well as ambient air temperature and humidity. Additional floor heating, e.g. with heat pumps, reduces detention time and footprint (See Fig. 11).

To avoid dust generation, the sludge is dried only to around 70%DS. Where biosolids are fed and removed with front-end-loaders, working conditions for their drivers are a concern. The air within the greenhouse contains pathogens. For this reason, and because of labor cost savings, sludge feeding and removal through screw conveyors is preferred.

Investigations by Horn et al. (2008) of a plant in Brisbane, Australia showed that it took between 15 and 25 days to raise the solids concentration from 20 to 75 %DS. Volatile solids were reduced by around 7 %, and the power consumption was below 50 kWh per ton of water evaporated.

Their investigations showed that sufficient Class A disinfection could not be achieved. Earlier investigations had shown that salmonella could be inactivated after 6 months of long-term storage and moderately resistant enteroviruses after 11 months, but 15 % of ascaris eggs still remained viable after 11 months (Haible 1989). Sufficient disinfection may be possible by addition of lime, but mass and operating costs would increase, and working conditions within a greenhouse would become more hazardous. A better option is to disinfect sludge before or after solar drying in a separate process.

Solar drying is an excellent option for small plants, particularly where sun radiation is strong and ambient air humidity is low, and where Class A disinfection is not required. Their footprint is significantly reduced by additional heating with heat from CHP systems or by use of heat pumps.

DISINFECTION (GENERATION OF CLASS A BIOSOLIDS) IN BELT DRYERS

Air temperature in medium-temperature belt dryers is selected between 75 and 140 °C (167 – 284 °F) depending on the temperature of the available heat source. CHP systems with gas engines, can supply two kinds of heat: heat from engine cooling, typically provided as hot water with a temperature of around 90 °C (195 °F), and heat from exhaust fume cooling, usually at a temperature of 150 °C (300 °F) or higher, either as hot water with a pressure of up to 0.5 MPa (72.5 psi) or as hot thermo-oil. It should be noted, however, that the supply of heat from CHP systems decreases with higher supply temperature. Most existing CHP systems with gas engines supply heat in form of hot water at a temperature of around 90 °C (195 °F).

The data in Figure 12 and 13 were measured at a medium-temperature belt dryer. Hot water from a CHP system is supplied with a temperature of 90 °C (195 °F). Heat exchangers are installed underneath each of the two belts. They heat the air immediately before it streams upwards through the belts and solids layers. Air temperatures were measured with a thermo-element directly above the solids. Solids samples were grabbed from the belts and chutes and immediately poured into a thermos. The temperature within the thermos was measured with a thermo-element. The solids detention time in the belt dryer was 150 minutes.

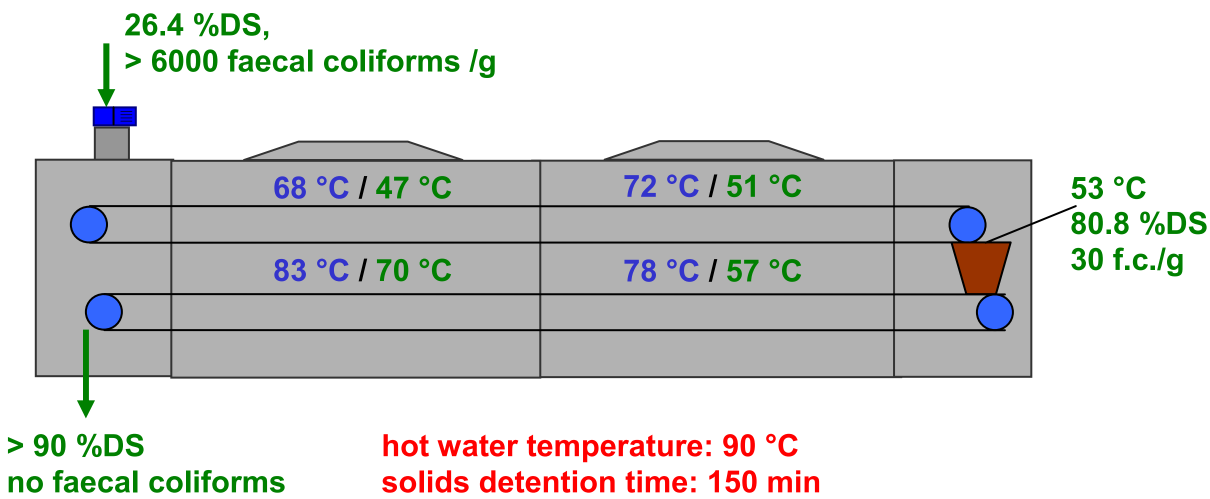

Figure 12: Air and biosolids temperatures in a medium-temperature belt dryer (HUBER)

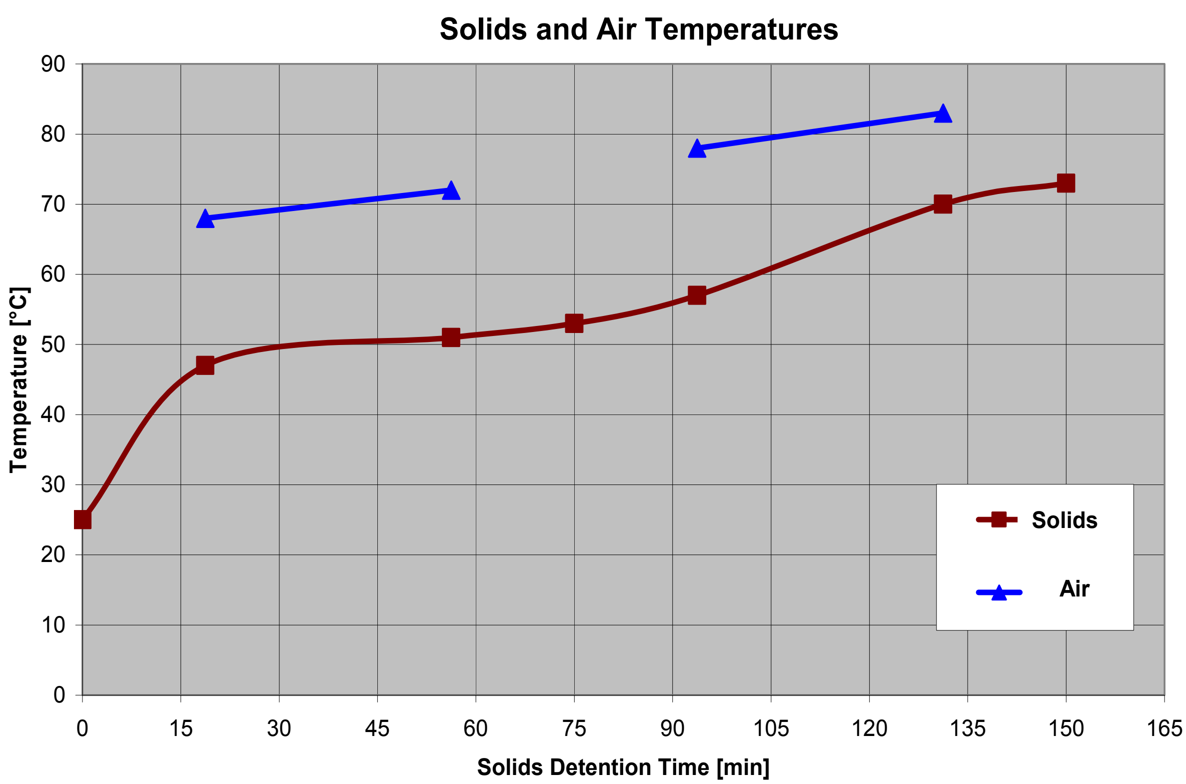

Figure 13: Air and solids temperatures in the investigated medium-temperature belt dryer

After the biosolids have been spread on the upper belt, their temperature rises rapidly to around 50 °C (122 °F). This is the heating-up phase. The high temperature difference between air and still wet solids results in good heat transfer, and the air streaming through the wet solids becomes rather cool. After about 30 minutes on the belt a steady-state temperature is attained, lasting until the end of the upper belt (75 minutes). The reason for the constant temperature is that much water evaporates from the solids and into the air. Its evaporation enthalpy prevents the solids temperature from rising.

On the lower belt, the solids temperature rises fast again. Most of the water has already been evaporated and the evaporation rate slows down. Solids temperature asymptotically approaches the air temperature. The air above the end of the lower belt remains hot. The solids temperature exceeds 70 °C (158 °F) from a certain point on the lower belt. With sufficient detention time, the biosolids reach a solids concentration of over 90 %DS and a temperature that is only slightly lower than that of the hot air.

US-EPA Part 503 Biosolids Rule (1994) states as Alternative 1 (thermally treated biosolids) and regime A or B (biosolids with 7% solids or greater) for meeting Class A disinfection the following tome-temperature relationship:

$$D = 131{,}700{,}000 / 10^{0.14*T}$$

Where D is the duration in days and T is the temperature in °C.

If the biosolids particles, as in our example, exceed a temperature of over 70 °C (158 °F), the required detention time at this temperature is 30 minutes.

Movement of the biosolids through a belt dryer is an ideal plug flow regime. All solids particles have exactly the same detention time in the dryer. Their detention time is exactly controlled through the belts' speed.

The solids temperature exceeds 70 °C (158 °F) over the last 20 minutes. This is only slightly shorter than the required 30 minutes. If the biosolids feed rate and the belt speed of the dryer would be reduced by only 10 %, the solids detention at 70 °C (158 °F) would be extended to over 35 minutes – well sufficient for meeting the time-temperature requirement.

The biosolids in the investigated medium-temperature belt dryer were analyzed for dryness, salmonella and faecal coliforms: The feed had 26.4 %DS, contained salmonella and over 6,000 faecal coliforms per gram of solids. The biosolids in the chute between the upper and lower belt had already 80.8 %DS, still contained some salmonella and 30 faecal coliforms per gram. The biosolids leaving the dryer had well over 90 % DS and neither salmonella nor faecal coliforms could be detected in the dried product.

HEATING WITH FOSSIL FUEL OR REUSE OF WASTE HEAT

Use of fossil fuel permits high-temperature operation of sludge dryers. The dryers are thus rather compact. Simultaneous Class A disinfection is easily achievable at high temperature.

Reuse of waste heat, e.g. from CHP systems, limits drying temperature to around 80 °C (176 °F). However, as we have shown before, it is well possible to achieve Class A disinfection at medium-temperature in belt dryers. They have a larger footprint than high-temperature dryers, but are far easier and safer to operate and maintain.

Use of fossil fuel for sludge drying is a waste of energy and an unnecessary source of CO_2 emission. Where no medium-temperature waste heat is available, a CHP system can be provided for its supply and simultaneous power generation.

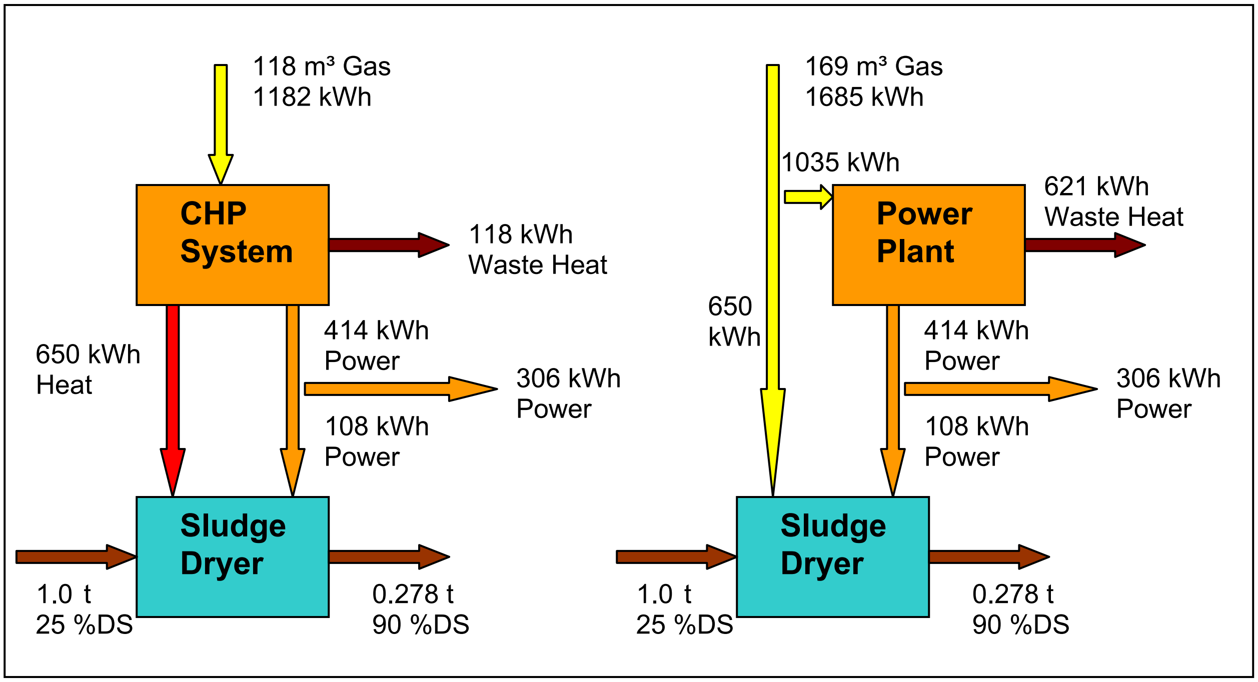

Figure 14: Medium-temperature heat from a CHP system in comparison with direct use of natural gas

Figure 14 compares the energy balance of both cases. We considered drying 1 metric ton of biosolids with 25 %DS to 278 kg with 90 %DS. We assumed that a CPH system has a power generation efficiency of 35 % and a medium-temperature heat generating efficiency of 55 % (the remaining 10 % being energy loss). We further assumed that power is generated from natural gas with an efficiency of 40 %.

The CHP system supplies 650 kWh heat for sludge drying (0.9 kWh heat per kg of water evaporated). This is generated from 118 m³ of natural gas, whereby 414 kWh of power are simultaneously generated. 108 kWh thereof is required for sludge drying (0.15 kWh power per kg of water evaporated). The remaining 306 kWh are fed into the power grid or used for other purposes on-site.

65 m³ of natural gas would be needed for fossil heating of the dryer. For generation of the same 414 kWh of power in a power plant, another 104 m³ of gas would be needed. This raises the total gas consumption to 169 m³. This is 43% more than the CHP system requires. The 51 m³ difference in gas consumption leads to a CO2 emission reduction by 100 kg. The effect is greater where power is generated from coal or oil

BELT DRYER REFERENCES

Table 1 includes some reference installations of three suppliers. The earlier HUBER installations are low-temperature, the newer ones are medium-temperature belt dryers. By far not all medium-temperature belt dryers in operation worldwide are included in our table. The suppliers KRÜGER and KLEIN refused to provide information.

Most systems dry anaerobically digested biosolids which are relatively homogeneous, have a low viscosity, are usually easy to dewater and emit little odor. The majority of the plants generates a product with around 90 %DS.

Installations that are operated at temperatures above 100 °C (212 °F) are either directly heated with fuel or hot gas, or indirectly via thermo-oil or steam. Dryers using heat from CHP systems are indirectly heated. Heat supply per mass of evaporated water of newer plants is 0.8 – 0.9 kWh/kg, independent of their temperature.

So far only few installations were required to generate Class A biosolids. Detention time and temperature are inversely related.

Table 1: Some Reference Installations of Medium-Temperature Belt Dryers

Location	Supplier	Com-missio-ning	Sludge Type	Heat Source	Product Use	Product %DS	Evap. Capac. t/h	Heat Supply kWh/kg	Air Temp. °C	Resid. Time Min.	Class A require-ment
Weinheim, DE	SEVAR	1991	Anaer. Dig.	Dig. Gas (direct)	Land + Landfill	80 – 92	1.6	1.15	120	45	No
Uttingen, CH	SEVAR	1993	Anaer. Dig.	Landfill Gas (indirect)	Land + Inciner.	90 -95	2.1	0.92	120	45	No
Colchester, UK	SEVAR	2002	Anaer. Dig.	Fuel Oil + Dig. Gas (direct)	Land	85 - 90	1.5	0.9	120	45	Yes
Schwyz, CH	HUBER	2003	Anaer. Dig.	CHP (indirect)	Inciner.	90	0.24	1.1	50	500	No
Wohlen, CH	AN-DRITZ	2004	Anaer. Dig.	Nat. Gas (direct)	Inciner.	90	0.75	0.8	140	?	No
Frohnleiten AT	AN-DRITZ	2004	Anaer. Dig.	CHP, (indirect)	Inciner.	90	1.2	0.8	110	30	No
Ingolstadt, DE	HUBER	2005	Anaer. Dig.	Waste Inciner. (indirect)	Inciner.	90	1.1	1.1	50	500	No
European Cement Factory, DE	AN-DRITZ	2005	Var. Sewage Sludge	Cement Kiln Exhaust (indirect)	Inciner.	90	7.8	0.7	140	30	No
Molerussa, ES	AN-DRITZ	2005	Anaer. Dig. + Fruit Pulp	CHP (indirect)	Land	90	3.2	0.8	110	30	No

IDELUX, BE	HUBER	2006	Munic. + industr.	CHP (indirect)	Inciner.	90	0.9	1.1	50	500	No
Altenrhein, CH	HUBER	2006	Anaer. Dig.	Effluent + Heat Pump (indirect)	Inciner.	90	2.3	1.1	50	500	No
Posidonia, F	AN-DRITZ	2006	Anaer. Dig.	Nat. Gas (direct)	Inciner.	90	2.15	0.7	140	30	No
Grudziadz, PL	HUBER	2007	Anaer. Dig.	CHP (indirect)	Gasifi-cation	90	1.05	0.9	80	150	No
Pfattertal, DE	HUBER	2007	Anaer. Dig.	CHP (indir.)	Inciner.	90	0.6	0.9	80	150	No
Göttingen, DE	SEVAR	2008	Anaer. Dig.	CHP exhaust (direct)	Landfill	60 - 80	2.25	0.9	120	40	No
Antalya, TR	AN-DRITZ	2008	Raw	CHP exhaust	Land	90	4.9	0.8	130	30	Yes
Dubai, AE	SEVAR	2009	Anaer. Dig.	Fuel Oil + Biogas (direct)	Land	90	10.5	0.9	130	50	Yes
Shenzhen, CN	HUBER	2009	Anaer. Dig.	CHP (indir.)	Inciner.	90	12	0.9	90	150	No
Straubing, DE	HUBER	2009	Anaer. Dig.	From Product Inciner. (indirect)	Inciner.	70	1.2	0.9	80	150	No
Shanghai, CN	SEVAR	2009	Re-finery	Steam (indirect)	Inciner.	65	0.77	0.9	130	45	No

SUMMARY: FEATURES OF MEDIUM-TEMPERATUR BELT DRYERS

The following list summarizes the main technical features of medium-temperature belt dryers:

- Relatively simple technology
- Larger footprint than that of high-temperature dryers, but far smaller than that of solar dryers
- Independent of climatic conditions
- Low wear and tear, due to slow belt movement and moderate temperature
- Continuous operation of fully automated plants
- Easy and quick start-up and shut-down
- Little dust generation in dryer - low risk of dust combustion and explosion
- Scrubber + biofilter for reliable deodorization of small exhaust air flow
- Moderate temperature facilitates use of waste heat, e.g. from CHP systems
- Product dryness adjustable between 65 and over 90 %DS
- Wider particle size range than that of drum or fluidized bed dryers employing product screening and recirculation
- Suitable for generation of disinfected Class A biosolids

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