A PROPOSAL OF HEAT PUMP APPLICATION IN AN AD PLANT WITH THP

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Abstract

It is proposed to integrate heat pumps to generate low pressure steam which can be used to preheat sewage sludge in a Cambi THP plant with two-stage preheating.

The proposal includes two key points. The first is to use water heat from CHP to generate low pressure steam via heat pumps; the second is to clarify that it needs work in a two stage preheating THP system which can be Cambi's conventional two-stage preheating THP or Cambi's new THP system which has no flash steam from reactors by adding a dedicated second stage heater to accommodate steam from heat pumps. For both of them inlet temperature of reactors can be improved higher than 100°C and then reduce total new steam consumption.

Respectively, based on design data of a project mainly treating SAS (75% SAS), the modelling demonstrates a reduction of 36% steam consumption and achieves a self-sufficient state (i.e. no external fuel needed, all steam required will be raised from CHP's waste heat boilers and from heat pumps thermally driven by LTHW).

Keywords

Thermal Hydrolysis Plant; Anaerobic Digestion; Absorption heat pumps

The design data of a THP-AD plant

The plant is supposed to treat 246t/d indigenous sludge (SAS only, 19%ds) and 139t/d imported sludge (26.92%ds). Totally, 84.2 tds/d, primary sludge and secondary sludge split is about 25%/75% (All figures are design data).

Thermal hydrolysis plant (THP) is chosen due to its double digester loading, improving biogas production and producing Pathogen-free and stabilized biosolids products with increased cake dewaterability in Anaerobic Digestion (AD) plant (Cambi, Unleash the power of anaerobic digestion).

The present process scheme is as follows:

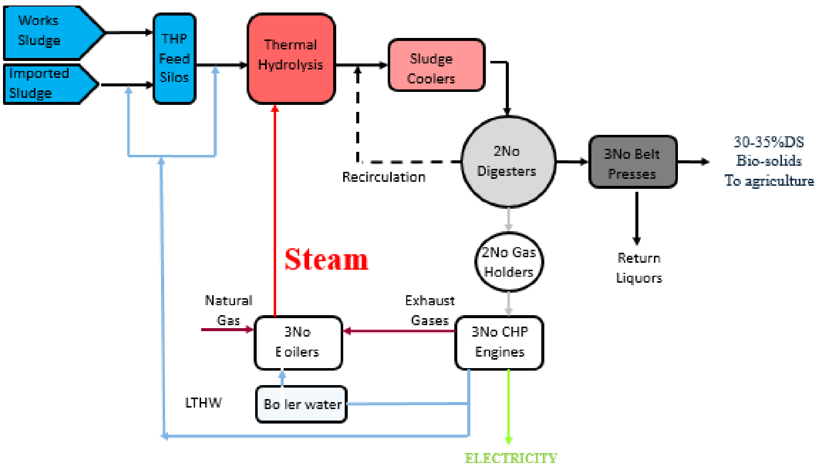
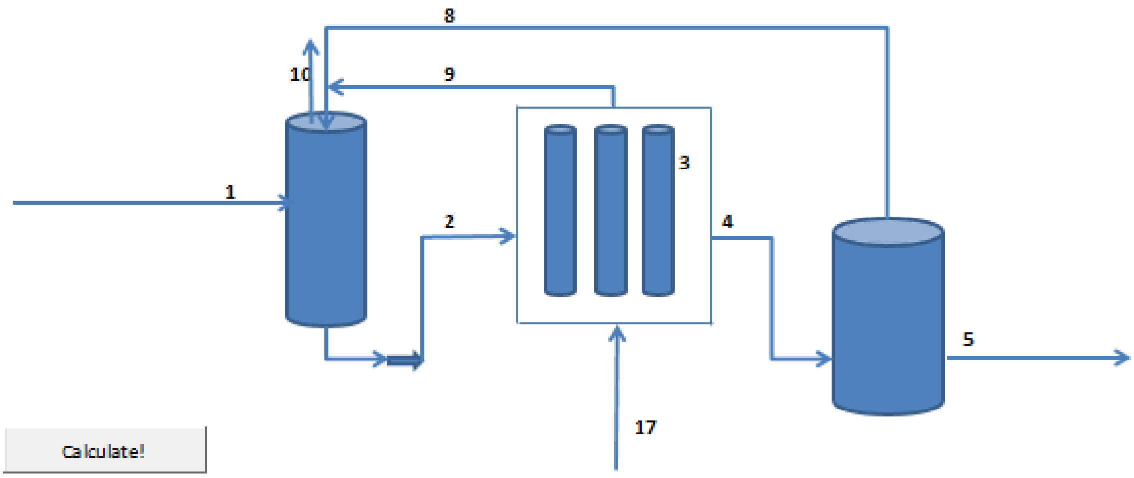


Figure 1: present process scheme

The indigenous and imported sludge are diluted by hot final effluent and fed to 2 lines of THP units, each of which includes one pulper, 3 reactors and a flash tank. In the THP plant, with new steam from 3 boilers, the sludge is kept at 165°C for 30minutes, it is then cooled down and enters digesters together with its recirculation. After digestion, digestate is dewatered via 3 belt presses while biogas flows to 2 gas holders. Biogas is primarily burnt in the CHP engines which generates electricity as well as producing heat. Heat lies in two forms, one is the flue gas, flue gas from each CHP engine goes through a dedicated heat exchanger in a composite steam boiler so that the waste heat recovered is used to generate steam (12 bara, 188°C), and the other is low temperature hot water (LTHW, 70/90°C).

An amount of water heat is used to preheat demineralized water and improve sludge temperature via heated final effluent diluting.

The detail THP scheme and mass balance is as following:



Stream Number	1	2	3	4	5	8	9	10	17
medium	sludge	sludge	sludge	sludge	ydrol. Sludg	Flash steam	eturn Stea	steam loss	New Steam
Dry solids (%DS)	16.50%								
Temperature ©	25	99.4	165	134	107.1	107.1	134	100	188
Pressure(bar a)			7	3		1.30			12
Flow(t/h)	21.24	24.1	27.4	25.6	24.3	1.3	1.7		3.227
Flow(kg/s)	5.90	6.70	7.60	7.12	6.76	0.36	0.48	0.03	0.90
Flow(l/s)	5.90								

Figure 2: present THP scheme and modelling result

The key processes in THP include:

(1) In pulper, the slurry can be heated by flash steam from both the reactors and the flash tank, it is designed to run under atmosphere pressure.
(2) Preheated sludge enters reactors with an injection of new steam (12bara, 188°C) and keeps the reactors at 165°C for 30min
(3) The steam in the reactors drops its pressure gradually and steam flows to pulper. Then typically when the pressure reaches approximately 3bara, the slurry in the reactors exits to the flash tank
(4) In the flash tank a sudden drop of pressure helps rupture cells of organic tissues and generates low pressure steam and low temperature slurry. The former exits to the pulper and the latter is mixed with recirculation from digesters and then cooled down in the downstream sludge cooler.

For the project, some key figures of design are as following:

Table 1: key figures of project design

	Unit	Data	Note
Total sludge after dilution	t/d	510	With dry solid content at 16.5%, approximately 84tds/d
Biogas consumption in the gas engine	kW	7378	LHV
Electricity generated	kW	3025	Based on Deutz engine, 41% power efficiency and 43% heat efficiency
Heat in the LTHW	kW	1579	Inlet/Outlet temperature: 70/90°C; Feedwater heating consumption (from 10°C to 70°C): 229kW; Inlet sludge heating via dilution, heat consumption (from 10° to 25°C): 283kW
Heat in the flue gas	kW	1601	
Natural gas consumption	kW	906	
Steam generation	Kg/s	0.91	12bar, 188°C. feedwater temperature 70°C. 90% boiler efficiency. Note: Split the contribution of fuel and exhausted flue gas, the latter's capable contribution:0.58kg/s steam
Heat in sludge cooler	kW	1914	Temperature drop from 107°C to 40°C is assumed.

Integrate heat pumps to generate low pressure steam for preheating in order to improve THP inlet temperature

From the above table, it demonstrates that AD plant needs intensive energy input from new steam whilst heat is needed to be discarded via a sludge cooler and LTHW system.

In order to reduce steam consumption, it is natural to ask how to make full use of the heat in LTHW and the sludge cooler. If the heat in the LTHW or sludge cooler can be converted to steam and used to preheat the sludge, the steam consumption from the boiler may drop then.

Absorption heat pumps (type II) can be driven by relatively low temperature liquids to generate steam. The principle scheme is as follows (Wijaya 2011)

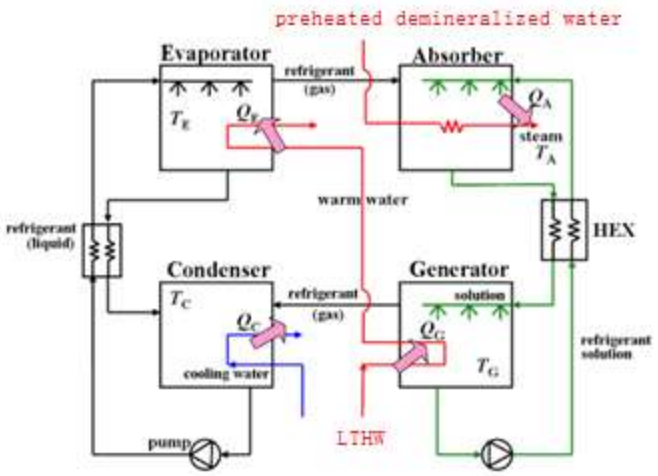


Figure 3: Heat pump principle scheme

Theoretically heat from both the LTHW (1579kW) and the sludge cooler (1914kW) can be used as heat sources. However, to avoid fouling in the pipes, the sludge downstream from the sludge cooler would better be cooled down quickly via recirculating sludge from digesters to 65-75°C, then dropped to 40°C in the sludge cooler before entering digesters.

The following analysis is assumed that only LTHW heat (70/90°C) is used to drive heat pumps. In order to produce maximum low pressure steam, the heat from the sludge cooler will serve all of the original heating demands, such as for demineralized water and diluting final effluent.

Note diluting final effluent temperature will be subject to the relatively low temperature of the sludge after merging with recirculation from digesters, which in turn will limit the highest temperature of input sludge after dilution. For this project, assuming 1.4kg/s diluting final effluent can be heated to 73°C, then inlet sludge temperature can be improved to 25°C.

The new system with integrated heat pumps is as follows:

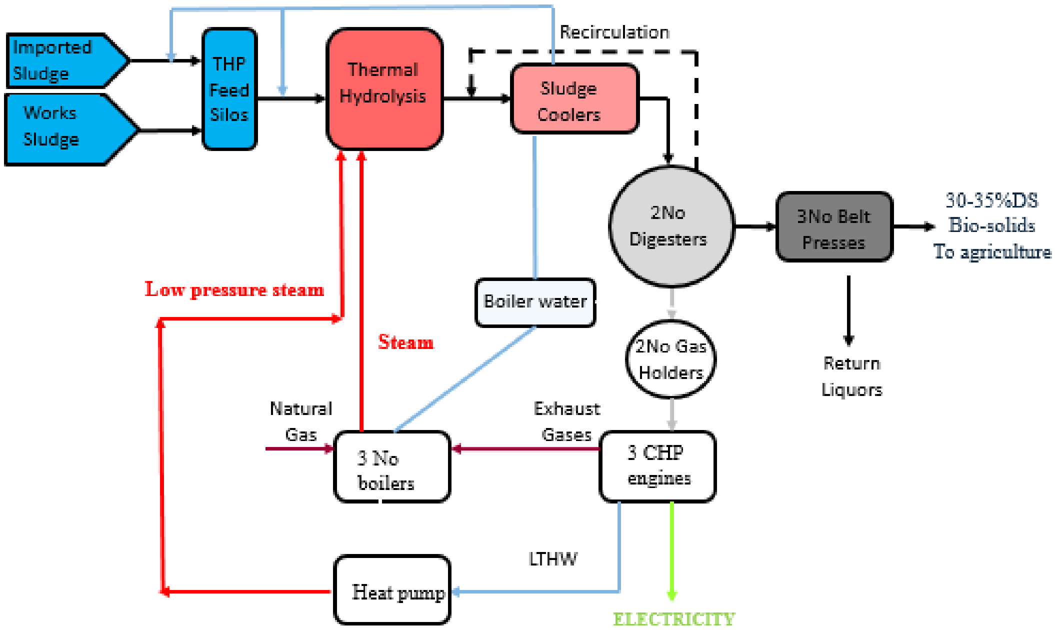


Figure 4: **Proposed energy use scheme**

Assuming 50% efficiency for the heat pumps (Ebara Corp. 2008), with 1579kW input, there will be 0.33kg/s steam@2.5bara, 125°C generated.

It doesn't match with one stage preheating THP system

Cambi has both THP technologies based on one stage preheating and two stages preheating respectively.

For one stage preheater, it is designed to run under atmosphere pressure. Sludge preheating can be regarded as two periods: first being heated by steam from reactors and then by flash steam from a flash tank. Note that the temperature of the former is about 133°C (3bara) while the latter one is about 107°C (1.3bara) which reflects the fact that the flash steam from the flashtank to the pulper must enter the pulper below liquid level in order to be able to condense (normally approximately 3 m).

Due to this heating sequence, according to the second law of thermodynamics----
Heat cannot of itself pass from a colder to a hotter body, the highest temperature exiting from pulper should be lower than the temperature of latter heating resource----flash steam from the flash tank, in practice, it is about 100°C.

So, for one stage preheating THP, the designed maximum output temperature from pulper is 100°C. New steam is used to improve it to 165°C and hold it for 30mins. Note, due to new steam and steam from reactors and flash tank, mass flow entering reactors is bigger than pulper's inlet flow. Because of this bigger mass flow, the same temperature drop during two periods of steam depressurizing can effectively result in a higher temperature raise for inlet sludge in pulper, for instance, if sludge temperature drops from 165°C (in reactors) to 107°C (downstream of flash tank), the temperature raise in the pulper then should be higher than 58°C, which indicates there should be a maximum inlet temperature for THP when complete heat recovery happens. Beyond this temperature, then incomplete heat recovery exists which can represent higher operating pressure in flash tank and then higher outlet temperature of total THP system.

The modelling shows that the maximum inlet temperature can be 25°C when flash tank runs at 1.3bara. If the temperature exceeds, then not all available heat from the steam flashed back from both reactors and flash tank will be recovered completely.

So even the latent heat of steam from heat pumps can make a rise of 29°C for the sludge in pulper, it will not help to reduce steam consumption which is essentially determined by temperature raise in reactors. This should be at least from 100°C to 165°C for one stage preheating THP.

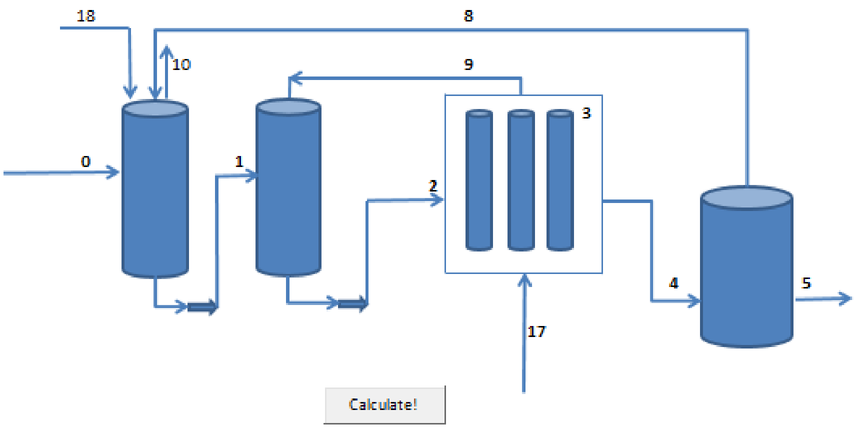
Two stages preheating THP and modelling result

Steam from heat pumps can work well with Cambi's two stage preheating THP system. It relocates the steam from the flash tank to a heater that is upstream of the pulper. Low temperature steam from both the flash tank and the heat pumps can then be used before the utilization of high temperature steam from reactors.

Modelling is organized based on the following boundary assuming complete heat recovery occurs:

(1) Temperature in the first stage preheater shouldn't exceed 100°C;
(2) Temperature in the second stage preheater (pulper) should be lower than the temperature of steam from reactors;

Modelling result is as following:



Stream Number	0	1	2	3	4	5	8	9	10	17	18
medium		sludge	sludge	sludge	sludge	Hydrol. Sludge	Flash steam	eturn Stea	team los	New Steam	Heat Pumps' Steam
Dry solids (%DS)	16.50%										
Temperature ©	25	86.9	125	165	133.5	107.1	107.1	134	100	188	125
Pressure(bar a)				7	3		1.30			12	2.5
Flow(t/h)	21.2	23.6	25.3	27.4	25.7	24.4	1.3	1.7		2.091	
Flow(kg/s)	5.90	6.55	7.03	7.61	7.14	6.78	0.36	0.48	0.03	0.58	0.33
Flow(l/s)	5.90										

Figure 5: modelling of Heat pump application together with Cambi conventional 2 stage preheating THP system

By integrating heat pumps to generate steam (0.33kg/s,) and use steam from reactors in the second stage preheater (pressurized pulper), inlet temperature of reactors can be improved to 125C which effectively reduces the steam consumption in the reactors. For this project, the new steam consumption can be reduced to 0.58kg/s, compared with original 0.90kg/s, achieves a reduction of 36%.

In addition, due to less steam heat in the first preheater compared to one stage preheating THP, its output temperature is much lower which indicates that theoretically a higher inlet temperature can be accommodated, modelling shows the highest inlet temperature can be 35°C, which in turn also helps achieve a smaller new steam consumption (0.47kg/s). However, due to the capacity of diluting final effluent mentioned before, a higher inlet temperature can't be achieved in this project.

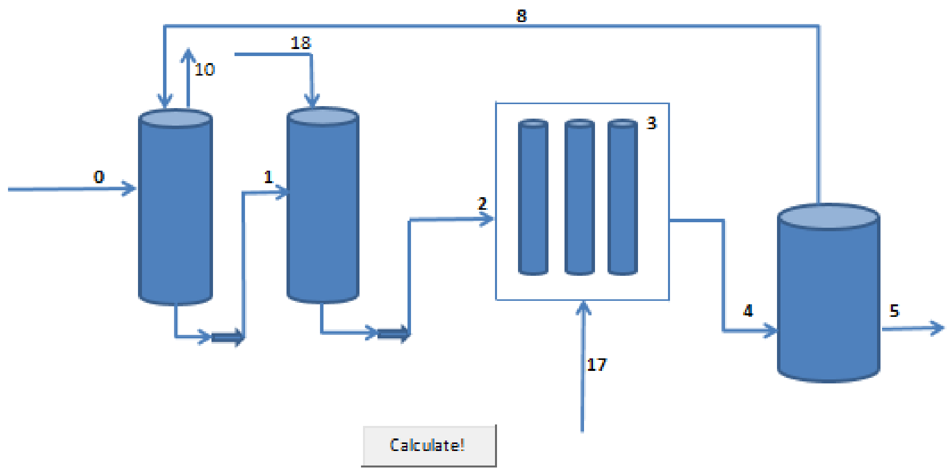
By the way, the pressure of steam from heat pumps should be adjusted to match with steam from flash tank before it enters the pulper.

Note, the capable contribution of steam from exhausted flue gas is exactly 0.58kg/s (refer to table 1) which means natural gas combustion in the boiler can be cancelled based on the heat pump proposal. In other words, it can become an energy self-sufficient system.

Working together with Cambi new THP system

Cambi developed new THP system which is featured with no flash steam from reactors in order to improve the steam explosion in the flash tank.

Based on above analysis, the highest outlet temperature from the pulper will be 100°C. By integrating heat pumps to generate low pressure steam and allocated it to the second stage heater will improve inlet temperature to reactors then effectively reduce new steam consumption. Modelling result is as following:



Stream Number	0	1	2	3	4	5	8	10	17	18
medium		sludge	sludge	sludge	sludge	Hydrol. Sludge	Flash steam	steam loss	ew Stear	Heat Pumps' Steam
Dry solids (%DS)	16.50%									
Temperature ©	25	99.6	124.9	165	165.0	107.1	107.1	100	188	125
Pressure(bar a)				7	7		1.30		12	2.5
Flow(t/h)	21.2	24.2	25.3	27.4	27.4	24.4	3.0		2.1	
Flow(kg/s)	5.90	6.71	7.04	7.62	7.62	6.78	0.84	0.03	0.58	0.33
Flow(l/s)	5.90									

Figure 6: modelling of Heat pump application together with Cambi new THP system

It demonstrates it will achieve the same effect like two-stage preheating THP system provided the same inlet sludge temperature. It also achieves an energy self-sufficient status.

Conclusion

By integrating heat pumps into AD plant with THP, LTHW from gas engines can be used to generate low pressure steam.

Co-operating with Cambi's two stage preheating system, steam from heat pumps and flash tank is used to preheat sludge before it enters pulper. In the pressurized pulper, high temperature steam from reactors improve sludge temperature dramatically above 100°C which results in a reduction of the new steam consumption in the reactors.

Working together with Cambi new THP which has no flash steam from reactors, steam from heat pumps can be allocated to the second stage heater (pressurized) which also helps improve sludge temperature to reactors and in turn reduce the new steam consumption.

Modelling based on design data of a project shows that it is possible to achieve an energy self-sufficient system in this mainly treating SAS THP-AD plant (75%SAS). It is likely that for other THP plants with more primary sludge, the situation can be even better.

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