Dynamic Pinch Analysis

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Needs for heating and cooling in Serbia is growing up. Existing systems in buildings and industrial processes are increasingly using renewable energy. To improve the competitiveness of the domestic economy, a great character given to improving energy efficiency. The paper analyzes the possibility of integrating technological processes with heating and cooling systems at the plant for production of mineral water. The aim is to improve the energy efficiency of the system both considered by mutual integration into a single system with the use of locally available renewable energy. Integrating is analyzed using a "pinch" analysis (methods of minimum temperature difference). The aim of this work is to improve the model by means of the acquisition of physical parameters and influence the process of exchanging heat of warm and cold currents were optimal energy-saving energy. The first part represents the composite and the cumulative curve in the case of an industrial process, and determines the state of the necessary energy in the summer and winter period and of the technological HVAC systems. The second part shows the variable pinch point in the summer and winter periods on the basis of changes in ambient temperature and technological process. Possibility of year-long use of geothermal heat pumps and geothermal energy.

Keywords: Heat Exchanger Networks, Methods of minimum temperature difference, Pinch

1. INTRODUCTION

Reducing production costs is one way of improving the competitiveness of the product (or company). In the sphere of energy, reducing production costs is reflected in the reduction of energy costs. These costs reduced by improving the energy efficiency of the production process. As a rule, improving energy efficiency was followed by a decrease in the emission of pollutants into the environment.
The company, whose manufacturing processes followed a large number of technological flows which can heat and cool, at the same time to improve energy efficiency flows associated heat exchangers. The goal is to maximize heat dissipation, which is subtracted from the streams that are cooled from streams which are heated. Maximizing heat exchange within the company as a result has a minimum consumption of energy for heating and cooling.
Pinch analysis of 80s [1,2] of the last century are used for optimal connection of production streams, which are at the same time heated and cooled. This method was the first applied in the petrochemical industry. According to this method, all flows in the company, all of streams who are heated, are seen as the cold streams and contrary, all the streams that are cooled are seen as warm streams.
The problem boils down to maximizing the exchange of heat between these two streams. This method is applied liberally and prosper so that it begins used for optimum energy mutual connectivity and more companies [3]. Papers [4,5] provide an overview of the latest developments in the field of integration of production processes. Into the Serbia there is great potential for thermal integration of production processes to improve energy efficiency in the food industry, in dairies, manufacturer of alcoholic and non-alcoholic beverages and food products. On the other hand, relatively large variations in ambient temperature requires heating and cooling of the administrative area of the companies as well as some production facilities to fulfill the prescribed conditions employee benefits.
The aim of this paper is that in the case of one company replied that it is possible to improve energy efficiency:

- better integration of the production process,
- integration of production processes of heating and cooling production and administrative space,
- integration of the production process and space for heating and cooling with geothermal heat resource available at the location of the test company.

Renewable energy should be a link that connects manufacturing and process of the heating and cooling into factory space and for providing: heat for heating, heat sink for cooling and heat accumulators.
By integrating all three links optimizes not the only the manufacturing process but he links in unbreakable whole with the natural environment in which it is located.
In this paper, are integrated production process, a process of heating and air-conditioning systems and geothermal energy in company "Knjaz Miloš" in Aranđelovac.
The aim is the creation of optimal energy system at the plant, which will operate efficiently throughout the year.
Therefore, it is tracked the changes of critical point (pinch) per annum and the paper defines a new concept: the dynamic (variable in time) pinch.

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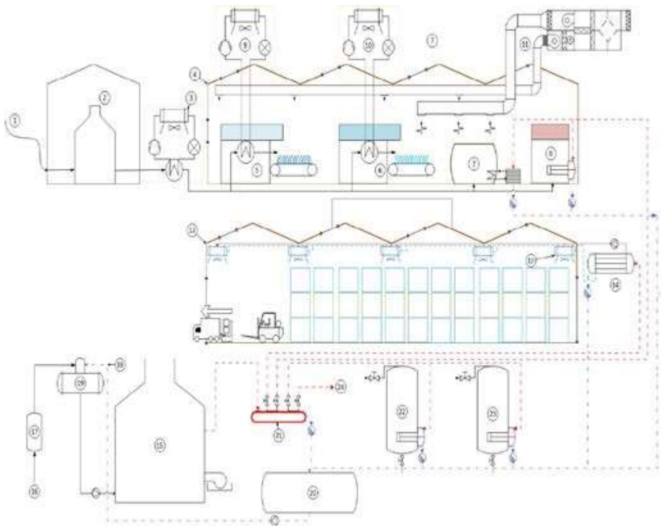

Simplified process diagram of the investigated "Knjaz Miloš" company, where: 1 is 7 km long uninsulated underground piping that connects a mineral water spring and the company, 2 – reverse osmosis with the mineral water accumulation tank, 3 – 1st stage of the mineral water cooling, 4 – PET hall (production hall), 5 – production line for PET bottles filling with the mineral water, 6- production line for glass bottles filling with the mineral water, 7 –energy drink production, 8 – molasses and juice production, 9 – 2nd stage of mineral water cooling (immediately before CO_2 absorption), 10 – 2nd stage of mineral water cooling, 11 – Air handling unit of the air conditioning system for the PET hall, 12 – warehouse, 13 – hot water fan coil system for the heating of warehouse, 14 – heat exchanger (steam/hot water), 15 – 3 steam natural-gas-fired boilers in the boiler room, 16- make up water, 17 – base exchange softening, 18 –condensate return, 19 – boiler feed tank, 20 – condensate tank, 21 – steam header, 22 – CIP washing, 23 – domestic hot water, 24 – branch towards the part of the company that is excluded from the analysis.

2. MODELING

Composite curve shows which is the minimum amount of energy necessary to take from the streams to be cooled and supplied to the flows that are heated, as well as the minimum temperatures heated fluid necessary in order to achieve the given heating and cooling of technological process. In the analysis of Pinch-a had been used assumption that is minimum temperature difference in the heat exchangers $\Delta t_{min} = 4°C$. The analysis shows that is: The critical temperature of the process at ambient temperature in the summer 36°C. This means that if there is a heat exchange with heat pump, streams that is simultaneously cooled and heated in the industry, heat pump (or heat pump system) has to take the heat below and above the critical temperature surrender.

As can be seen from the diagram composite blame a lot of power, which is below the Pinch-a - it is necessary to cool, while a small part of above of Pinch and need to be heated to the high temperatures. So, the problem is where to submit this excess heat. Project solutions, with acquisition of variable Pinch-in a given time points and influencing exchange process heat and cooling energy, it is possible to make a "stream networks" with as more even distribution of energy. When we say "stream networks" primarily refers to the optimal power flow heat exchanger and appropriate automatisation of streams that flows. temperature and fluid flow participating in the heat exchange. There are two conditions in an industrial plant that must comply with the following:

- Technological process
- Specify conditions in HVAC (internal design conditions HVAC)

Any change of Pinch and the impact on the process of heat exchange, must meet the above two conditions, and to there by achieve energy saving with constantly monitoring theory Pinch and that:

Do not use cold side above the Pinch
Do not use hot side below the Pinch
Do not use heat transfer through the point Pinch

For stacking flows, there are the following two rules: In the section above the Pinch, the number of warm streams (including their branches) should be smaller or equal to cold flow (including their branches), such that:

$N_h \leq N_c$ (above Pinch)

Otherwise, the flow separation is necessary to provide full given condition.

Similarly, the area under the Pinch-a is an inverse inequality

$N_h \geq N_c$ (under Pinch)

For the part above the Pinch-a warm stream (or branch of warm streams) should be less than or at least equal to that cold streams (or branch cold flow) should correspond, so that:

$(\dot{M}c_p)_h \leq (\dot{M}c_p)_c$ (under Pinch)

For part of the area under the Pinch, reign inverted inequality,

$(\dot{M}c_p)_h \geq (\dot{M}c_p)_c$ (under Pinch)

2.1. The basis for defining dynamical Pinch

The input data for the algorithm:

- Initial (supply) temperatures,
- Final (target) temperatures,
- Heat capacity flow rates,
- Minimum temperature difference

Value of output sizes are:

- Temperature,

- Heat flow at pinch.

The following shows an algorithm for the determination of dynamic Pinch.

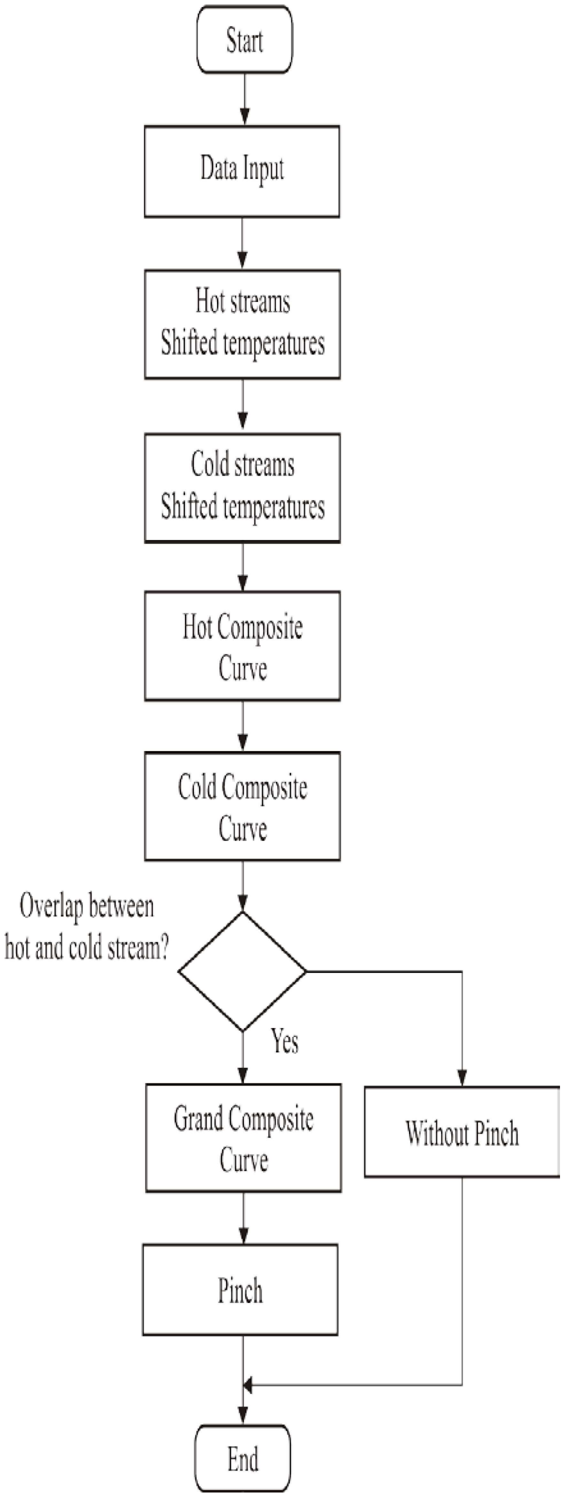

Figure 1: Algorithm Dynamic Pinch

2.2. Composite curve and Grand composite curve summer

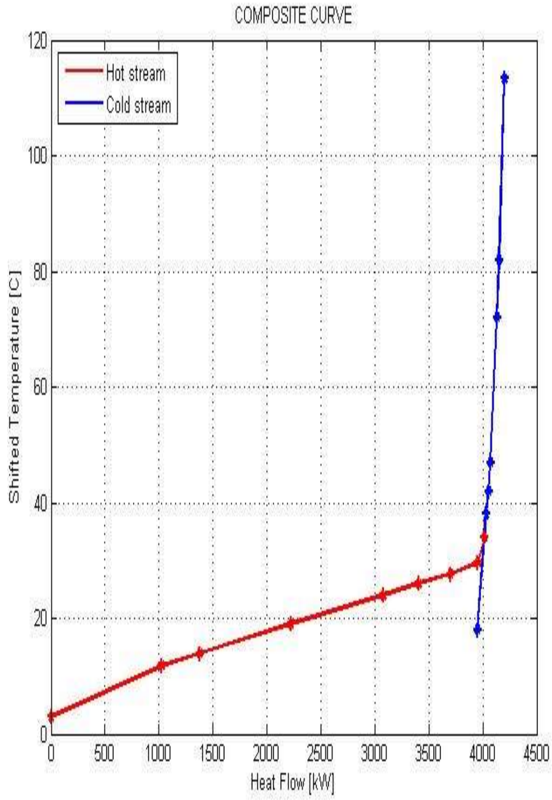

Figure 2: Composite curve (summer period)

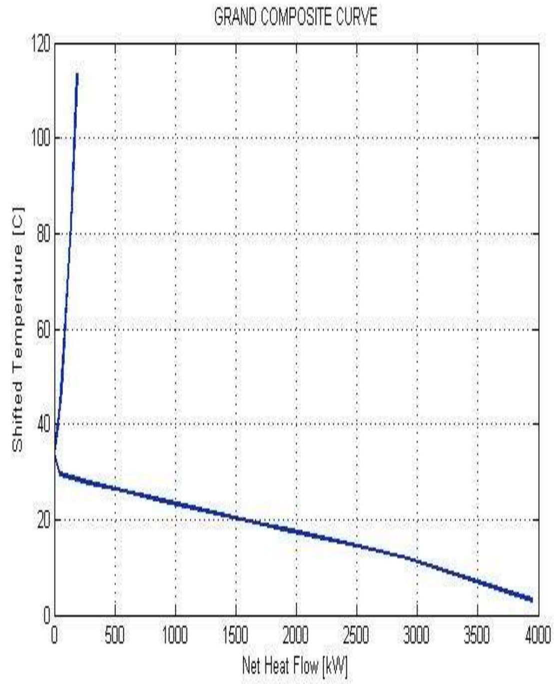

Figure 3: Grand Composite curve (summer period)

Figure 4. Grand Composite curve. Changing the air temperature in the Company data into the function:
Tts(1,1)=29.63+6.9•sin(2•π•T(k1)/Tk)

Watching the air condition part into the part off Company, the production hall has largest dissipation of heat from the production process. Also, had to had taken into consideration the heat gain in the summer. The sum of two sources is the total energy cooling balancing in the summer. The internal temperature and humidity in the room must not exceed the values that disrupts the basic environmental conditions for people. However, if it is simulating temperature changes, and thus the consumption of the cooling capacity of the constant value of the heat capacity of the stream gives the following parameters and the cumulative composite curve.
Changing of the temperature of air in Company may be simulated with a sinus function:

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Tts(1,1)=29.63+6.9•sin(2•pi•T(k1)/Tk)
Tts=[29.63 13.8; 31.6 5; 36 28; 26 16; 36 21]
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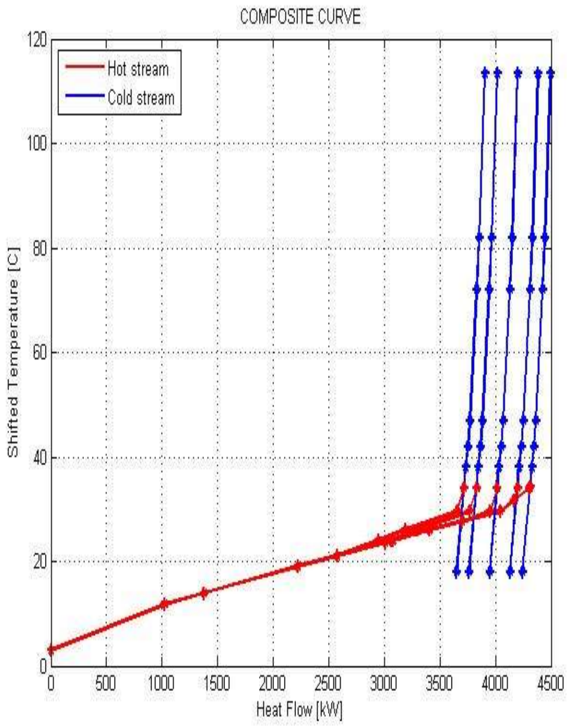

Figure 5. Composite curve. Temperature changes in HVAC area: Tts(1,1)=29.63+6.9•sin(2•π•T(k1)/Tk)

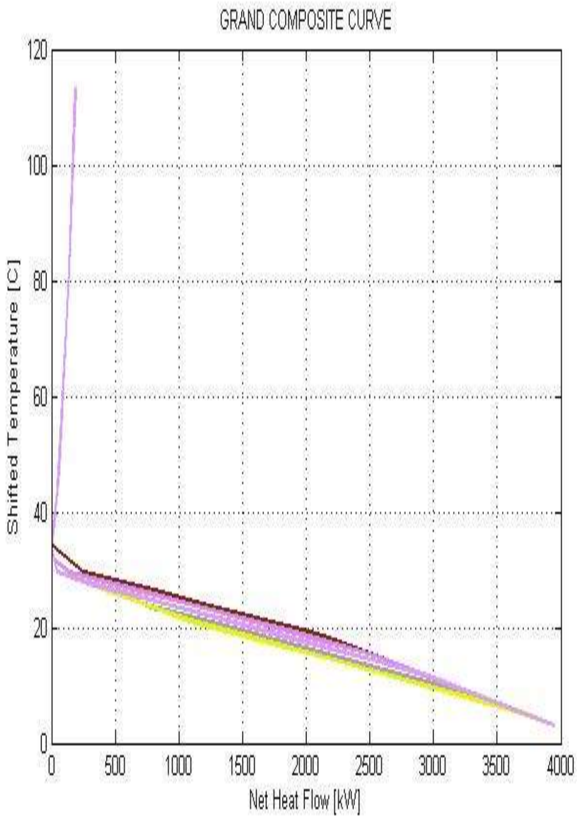

Figure 6. Grand Composite curve. Start point - and point temperature changes in HVAC area :
Tts(1,1)=29.63+6.9•sin(2•π•T(k1)/Tk) i
Tts(1,2)=13.8+6.9•sin(2•pi•T(k1)/Tk)

Regardless of the change in start points, and end points temperature of air in the installation of air conditioning, Pinch point is not moved. Its scroll occurred only when the air temperature is higher than the ambient temperature.

From the cumulative curves can be seen requisite for cooling capacity below Pinch.

Refrigeration consumption decreases and increases with temperature differential. The daily temperature fluctuations depends on two factors:

- External temperature in the summer during 24h and,
- dissipating heat heating machines in the plant.

In any case, the temperature changes are visible, except concerning individual monitoring does not lead to crucial changes. This is important for the HVAC system precisely, flow manage of cooling energy as an option for the volumetric flow of fresh air and circulating air in the cooling unit through a closed system of automatic control.

On further analysis, we can determine whether HVAC affects the overall energy picture into Company. Which model can be turned to the optimum distribution of cooling and thermal energy. Perceive coupling HVAC and technological processes.

It is particularly interesting to see changes into slope of cumulative and composite curves, by the change of fluid flow into the Company.

Daily fluctuations in energy and energy state of the productions of mineral water (to market products related industries, changes in climate on a daily basis, seasonal and annual, of discomfort that does not include a variety of design solutions, and enter the sum of energy, etc.).

By measuring accurately predicted parameters of temperature and flow measurement of all fluids, which are the main carriers of energy at any time we can gain picture in a realistic time where and when changes occur Pinch.

When it identifies changes of the Pinch and changes in the slope of composite and cumulative guilty in the industry, it can be promptly affect onto the streams flows and redirect energy exchange in a way that requires a theory Pinch-a.

Furthermore, it is interesting to observe the mathematical parameters of a real change of current flows of technological processes. It is noteworthy that the flow of heat capacity in certain areas of technological processes may be changing for several reasons.

The first reason of the changes of the masses flow of water from the water resources of the ground, as well as the temperature that is at the beginning of the process and at the end of the process is in the fact that during the process of manufacturing a need for production capacity is changing. This can be justified by market needs during the production cycle. The second component, the temperature, changes throughout the day and seasons depending on the time of year. Transporting fluid in the piping may be exposed to natural (weather conditions, etc.). Chillers, active cooling in the industry, not stationary process. Unsteadiness cause various disorders in the work. Each disorder leads to temperature changes in the fluid.

This is a prelude to further analysis which will show changes in the energy state of working fluid, which mainly affects the overall thermal and cooling consumption.

According to the parameters given in practice and samples of the particular case, we can say with certainty that in the installation can be applied višestepni transfer of heat and cooling energy, all depending on the current energy situation of the Company.

Here are primarily think on the optimization of the cooling towers, air - water heat pumps , water-water geothermal heat pumps, gas-turbine power-plants, solar collectors, etc..

Now let's introduce changes in the equation initial and final temperature of mineral water, but leave out change the temperature in HVAC.

Tts=[29.63 13.8; 31.6 5; 36 28; 26 16; 36 21];
%Tts(1,1)=29.63+6.9•sin(2•π•T(k1)/Tk)
%Tts(1,2)=13.8+6.9•sin(2•π•T(k1)/Tk)
Tts(2,1)=31.6+10•sin(2•π•T(k1)/Tk))
Tts(2,2)=7+2•sin(2•π•T(k1)/Tk)

Here we show only a change Pinch-and without changes in temperature due to the volume of data.

It is easy with a particular programming language to get the value of addressing the above equations to the appropriate place.

From this we can conclude that the value of the Pinch-a changed when the temperature of mineral water has reached a value greater than ambient temperature. This means that for the installation of the factory, now the temperature of the Pinch-not determined ambient temperature (outside air temperature at a given time). This can be attributed to exposures of the sunrays to the energy pipelines, directly. Indirect exchange of solar energy radiated on the outer piping, leads to increase in temperatures mineral water above the critical temperature of the environment, ie. its daily peak.

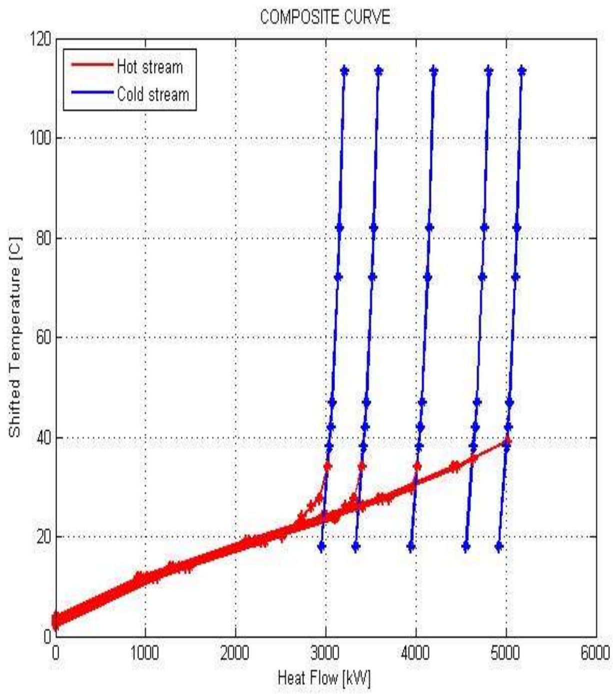

Figure 7. Composite curve. Temperature changes in mineral water process:

Tts(2,1)=31.6+10•sin(2•π•T(k1)/Tk)

Tts(2,2)=7+2•sin(2•π•T(k1)/Tk)

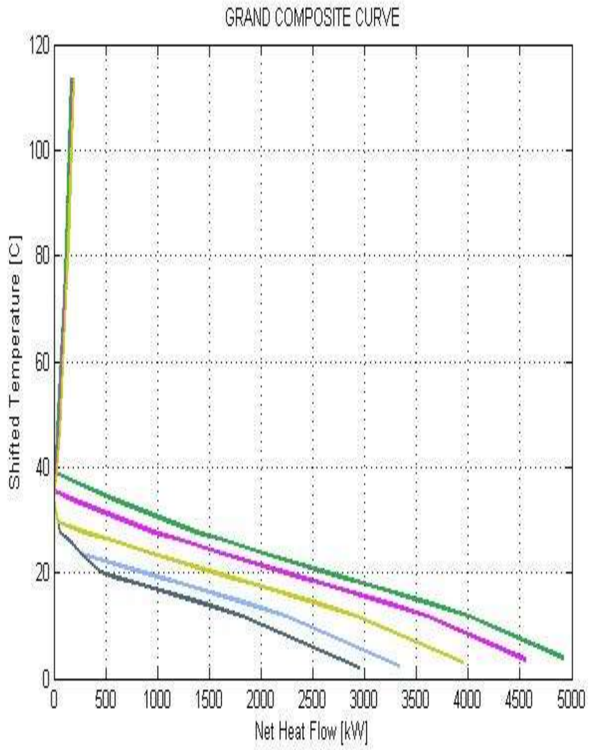

Figure 8. Grand Composite curve. Temperature changes in mineral water process:

Tts(2,1)=31.6+10•sin(2•π•T(k1)/Tk)

Tts(2,2)=7+2•sin(2•π•T(k1)/Tk)

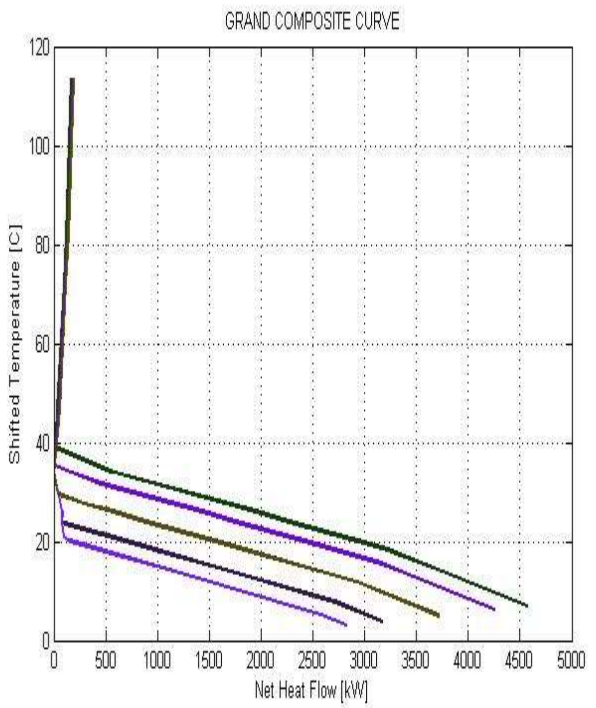

Figure 9. Grand Composite curve. Temperature changes in mineral water process and HVAC area:

Tts=[29.63 13.8; 31.6 5; 36 28; 26 16; 36 21];
Tts(1,1)=29.63+6.9•sin(2•π•T(k1)/Tk)
Tts(1,2)=13.8+6.9•sin(2•π•T(k1)/Tk)
Tts(2,1)=31.6+10•sin(2•π•T(k1)/Tk))
Tts(2,2)=7+2•sin(2•π•T(k1)/Tk)

3. DYNAMIC WINTER PINCH

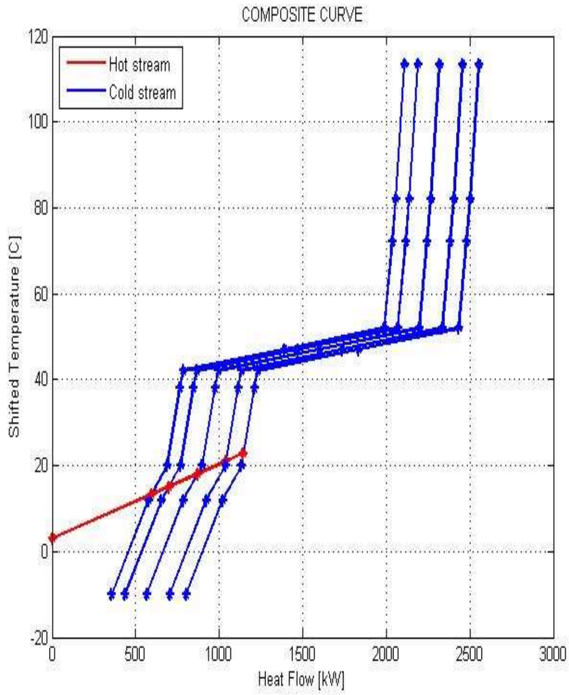

Figure 10. Composite curve winter.
Tts(1,1)=20+5•sin(2•π•T(k1)/Tk)

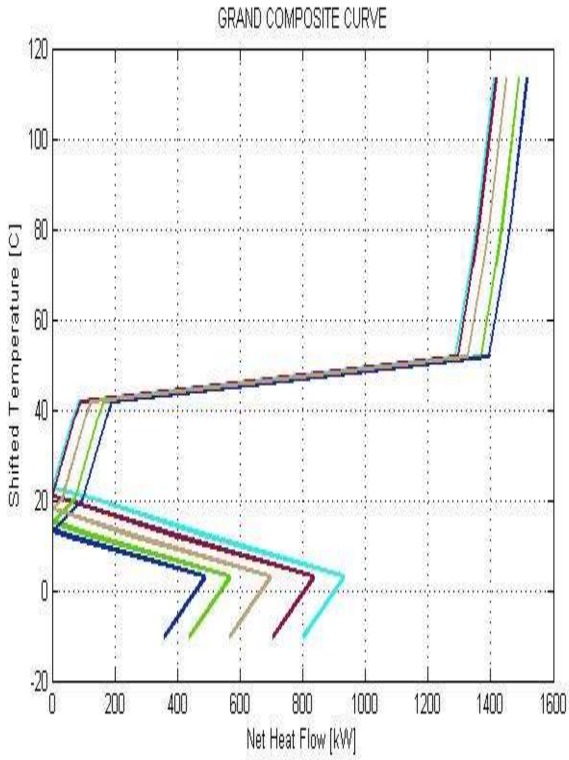

Figure 11. Grand Composite curve winter.
Tts(1,1)=20+5•sin(2•π•T(k1)/Tk)

Temperature changes in the technological process significantly affects the temperature change Pinch-a. Flows which are cooled, with warm stream in the winter significantly affect on change Pinch.

From the diagram of the composite curve ratio of heat and cooling consumption is far better that is not a huge difference between the flows that are heated and cooled by. The diagram shows that the percentage of energy that is required to be deducted by the cold currents and to surrender to the other side of the warm stream is more evenly distributed.

Naturally, needs for heating in winter is greater, especially when it cools and warms at the same time.

Here we see that at lower temperatures from 3˚C to 52˚C needs for cooling and heating is 1.395,00kW, of the total heat capacity 1,515.00 kW at a temperature of 113,4˚C.

Therefore, the need for heating at low temperatures (which corresponds to the temperatures of the heat pump water/water), indicates that it may be fulfilled with ~ 92% share of the heat consumption.

However, it is important to look variables temperature Pinch-a that match active compressor cooling or passive evaporative cooling system - use of energy of the environment in the process of cooling in the winter.

Here the question is, when and how much is needed to activate the passive cooling system in relation to the active system cooling of the compressor and activating another energy source for heating plant and production process.

The most important thing is to determine the system and take the control to him that would not arise inverse processes above or below the pinch-and during work process.

It should show slope of the composite and cumulative curve for different load cases.

Make mathematical dependence and optimize process.

Further analysis will show all the possible variables in the process.

With the given mathematical model is necessary to determine the energy situation in the system which would be a starting point for possible monitoring and automatisation cycle in operation, with a greater energy savings.

In addition, the technological process during the production process changes the mass flow of the filling line. Flows that are cooled (cold current). The data changes can be summarized by the following equations:

dTmin=4;

Flows that heat (cold stream)

Ths=[10 111.38; 36 111.38; 10 40; 10 70; 10 45; 10 80; 40 50; -12.1 18;];
CPHs=[0.64 0.992 1.617 0.24 1.16 0.509 117.43 9.95]';

%Heat Capacity flowrate [kW/K]

Flows that are cooled (thermals):

Tts=[20 5;];
Tts(1,1)=20+5·sin(2•π•T(k1)/Tk);
%Tts(1,2)=8+3·sin(2•π•T(k1)/Tk)
CPTs=[58]'; %Heat Capacity flowrate [kW/K]
CPTs(1)=58+35·sin(2•π•T(k1)/Tk)

Move of phase in heating and cooling technological process and the external temperature:

Tts(1,1)=20+5•sin(2•π•T(k1)/Tk -2);
Tts(1,2)=8+3•sin(2•π•T(k1)/Tk -2);
Ths(8,1)=-5+7.1•sin(2•π•T(k1)/Tk +3)

Diagrams of the phase shifted in heating and cooling:

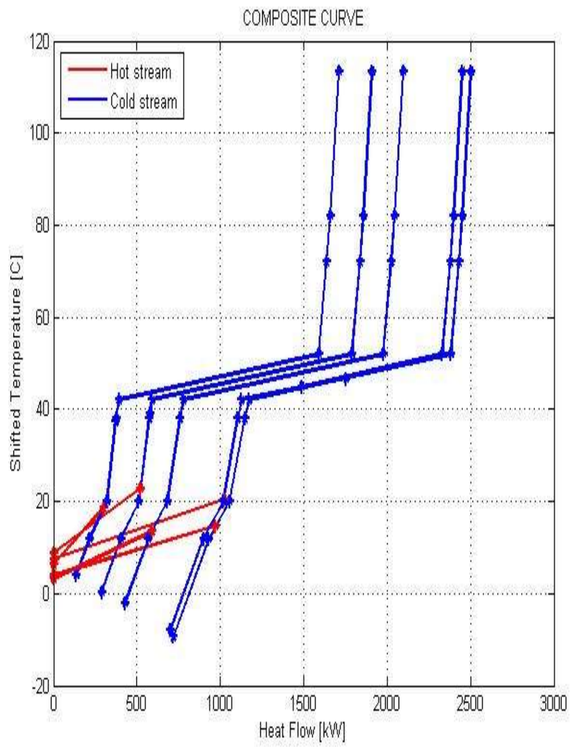

Figure 12. Composite curve with phase change winter.

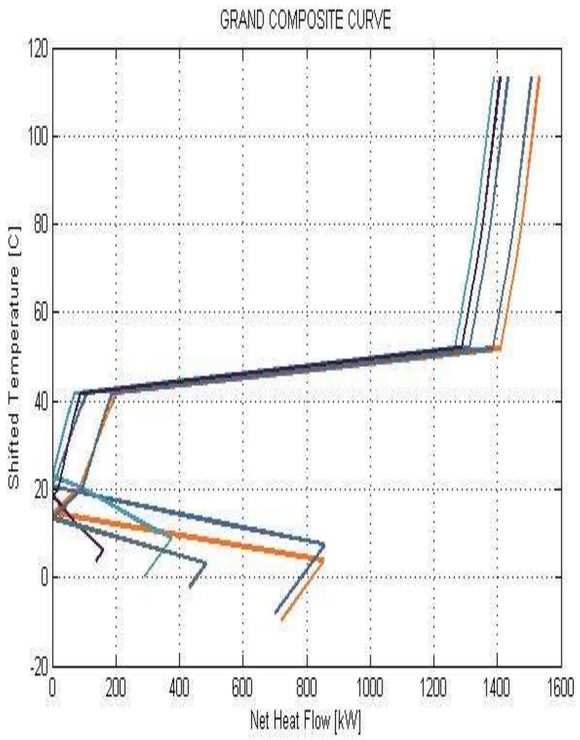

Figure 13. Grand Composite curve with phase change winter.

$$\theta_A = \theta_{Am} \cdot \sin\left(2 \cdot \pi \cdot \frac{\tau}{\tau_0}\right)$$ Where was given:

θ_A - temperature changes;

θ_{Am} - the amplitude of the temperature changes;

τ - time;

τ_0 - time temperature periods;

4. CONCLUSIONS

To determine the critical temperature for the use of different heating and cooling in the winter, so continuous monitoring of the temperature of the Pinch, of the environment (air and water), then the value of the heat and refrigerant of consumption through the tangens of the angle of inclination of hot and cold currents, and its absolute value.

Let consider a given data point Pinch-a.

The range in this case is 13,45˚C - 22.9˚C. That are physical size which are showen earlier in the winter period represented cumulative and composite curve. When using a heat pump water-water, with a constant temperature water source out of the ground (considered to be a very small change in the temperature of the groundwater as compared to temperature changes) can be taken following relation:

$T_{pinch,critica} = T_I = T_w = T_{environment} - \Delta T_{min}$ - energy used for first degree of cooling (energy groundwater in an open system heat pump water to water).

$T_{pinch,critical} \leq T_w$ i $T_{II} < T_{environment} - (\Delta T_{min} + \epsilon)$ uses the energy of the second degree of cooling (energy from the air "passive cooling" air system - glycol). The coefficient depends on the characteristics of the air exchangers - glycol and the setpoint temperature Tt extreme temperature processes.

If the ambient temperature equalizing with T_{II} , the process should been stop and moves on I level cooling.

It is important to note that from Figure 13 shows that for lower temperature of the Pinch temperature of groundwater ~ 15 °C, needs for cooling process is minimal, precisely between 200kW and 300kW, a heating demand is much greater than 1200kW to 1400kW at lower temperatures up to 52°C.

Using the second degree of cooling is favorable because it reduces the power consumption of the compressor. For the practical needs of small cooling capacity better uses passive cooling, while for heating and other conventional heat, use such as gas.

Pinch point tracking paving the way for redirecting of the stream fluid, their measuring, switching on and off of the energy systems and monitoring energy consumption at any given time.

REFERENCES

[1] Linnhoff B, Mason DR, Wardle I (1979) Understanding heat exchangernetworks. Comp Chem Eng 3:295–302

[2] Kemp I C, Pinch Analysis and Process Integration, 2nd edition, Elsevier, Amsterdam, London, New York, 2007, 415 p.

[3] C.L. Chang, X.L. Chen, Y.F. Wang, X. Feng, An efficient optimization algorithm for waste heat integration using a heat recovery loop between two plants, Appl. Therm. Eng. 105 (2016), pp. 799-821

[4] Editorial board, New developments in Heat Integration and intensification, including Total Site, waste-to-energy, supply chains and fundamental concepts, Applied Thermal Engineering 61 (2013), pp. 1-6

[5] Editorial, board, Recent developments in applied thermal engineering: Process integration, heat exchangers, enhanced heat transfer, solar thermal energy, combustion and high temperature processes and thermal process modelling, Applied Thermal Engineering 105 (2016), pp. 755-762