Drying of Forest Industry Sludge for Energy Production With Partial Vacuum Technology

Antti Vanhatalo, Helsinki University of Technology
Pekka Ahtila, Helsinki University of Technology

ABSTRACT

At the present time in Finland, primary and biological sludge formed during the pulp and paper manufacturing process is in most cases destroyed in bark-fuelled boilers. Disposal of sludge in landfills is minimized because of the environmental effects and in order to avoid extra expense. Because of the high water content, the heating value of the sludge is low. The quality and usability of sludge can be improved by drying.

In this research we try to rationalize the dewatering process of the activated sludge. While primary sludge contains fibers, activated sludge is composed of biological microorganisms that accumulate in activated sludge treatment plants during wastewater purification. Activated sludge is also called secondary sludge or biological sludge. The conventional mechanical dewatering process of activated sludge is not adequate if we want to produce heat with activated sludge. In pilot evaporation tests activated sludge was dried to a composition of up to 50-80% dry solids content. In theory, the burning process of sludge in a bubbling fluidized bed with over 40% dry solids content doesn't need support fuel.

Evaporation under partial vacuum conditions makes it possible to make good use of secondary heat in an evaporation process. In a partial vacuum, water evaporates even in temperatures below 40 °C. In pilot tests the evaporation temperature was 50 °C.

Utilization of free energy extracted from secondary heat facilitates profitable investments in activated sludge drying. Secondary heat can be obtained from low temperature flue gas, vapor and water flows. In modernized pulp and paper mills, utilization of low temperature secondary heat in sludge drying helps us to achieve an even higher degree of process integration and also to minimize fossil fuel consumption.

Introduction

The integration of cellulose and paper manufacturing in the forest industry has increased the efficiency of utilizing secondary heat flows inside the forest industry plants. Finland is among the most advanced countries both in the development and use of energy efficient technology and in process integration. In Finland about 80% of cellulose is manufactured in the integrated pulp and paper mills. More efficient production processes and a minimization of fresh water consumption will in the future raise the heat content and temperature level of secondary heat flows. Secondary energy is already effectively utilized, and finding a new process in which the low temperature excess secondary heat can be profitably eliminated is difficult.

Simultaneously, handling the sludge that originates from the manufacturing processes is an increasing problem, especially in the case of activated sludge, which consists mainly of biomass accumulating in activated basins, in the biological water purification process. The highest dry solids content that can be achieved with mechanical dewatering of activated sludge is about 20%. If a higher dry solids content is required, thermal drying is essential. Thermal drying of wet activated sludge with primary heat is an expensive method, because the evaporation of the water requires a lot of energy. Irrespective of the final disposal method, it is important that the sludge is as dry as possible because the high water content makes handling the product very difficult and expensive. Figure 1 shows the mass flow of the sludge as a function of dry solids content.

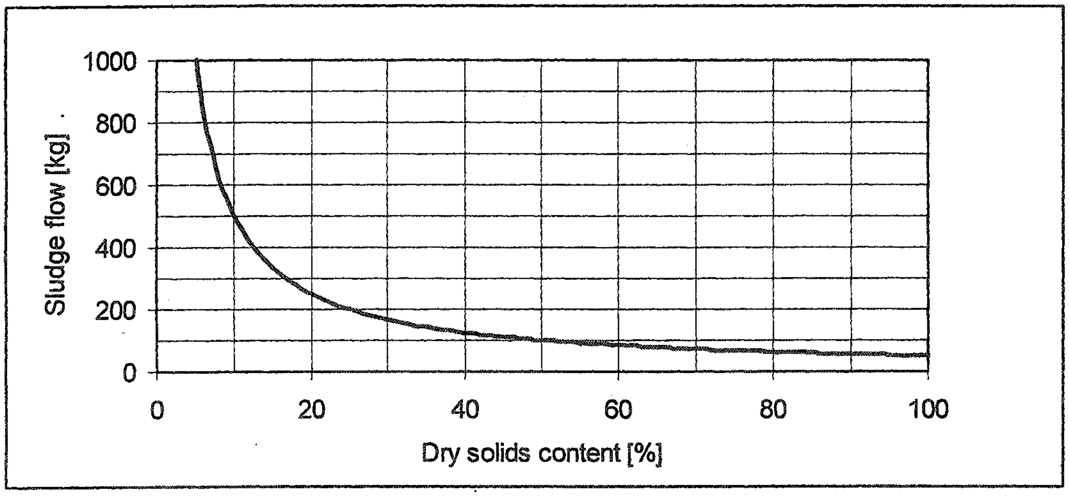

Figure 1. Sludge Flow in Proportion to Dry Solids Content

The most remarkable environmental challenge in the future may be how to handle and dispose of the waste that is produced in the purification process of the process effluents. At present, the high water content of the activated sludge is the main limitation on a more efficient use of sludge in energy production. Burning wet sludge reduces the burning capacity of the boiler and the heat recovered from it. More sludge could be burnt in a more efficient way if the dewatering and drying processes were more effective.

The effective heating value of the sludge is negative when the dry solids content is under 20%. The heat energy that is produced in sludge burning is needed for the evaporation of the water content, so additional fuel is needed to achieve the required combustion environment. When the dry solids content of the sludge is 40%, the effective heating value of the sludge is about 5 MJ/kg, which means that supplementary fuel is not required if the boiler is otherwise controllable (Isännäinen 1994). A bubbling fluidized bed boiler, for example, can manage bio fuels with low heating value. The drying of activated sludge may turn waste that has to be destroyed in the boiler into useful and valuable bio fuel. Improvement in the quality of the fuel provides a better environment for the burning process, and this in turn leads to emission reduction, including a reduction in CO_2 emissions.

In Figure 2 we can see that the effective heating value of dry activated sludge is almost as high as that of dry peat and dry bark. If wet sludge is burned in a boiler, then the whole water content of the sludge must be evaporated in the boiler with high-temperature primary energy. In this way, part of the primary energy is used for drying, so valuable heat that could otherwise be used in electricity production, for example, is lost. In some cases the burning capacity of the boiler may be so critical that the mill would have to invest in a new boiler to guarantee the required energy production when burning wet sludge. Using free excess secondary energy for drying makes the thermal drying process competitive. Evaporation in a partial vacuum utilizes free low exergy energy in temperatures between 60 °C and 80 °C. In many cases the value of these heat flows is even negative because the heat must be removed from the process.

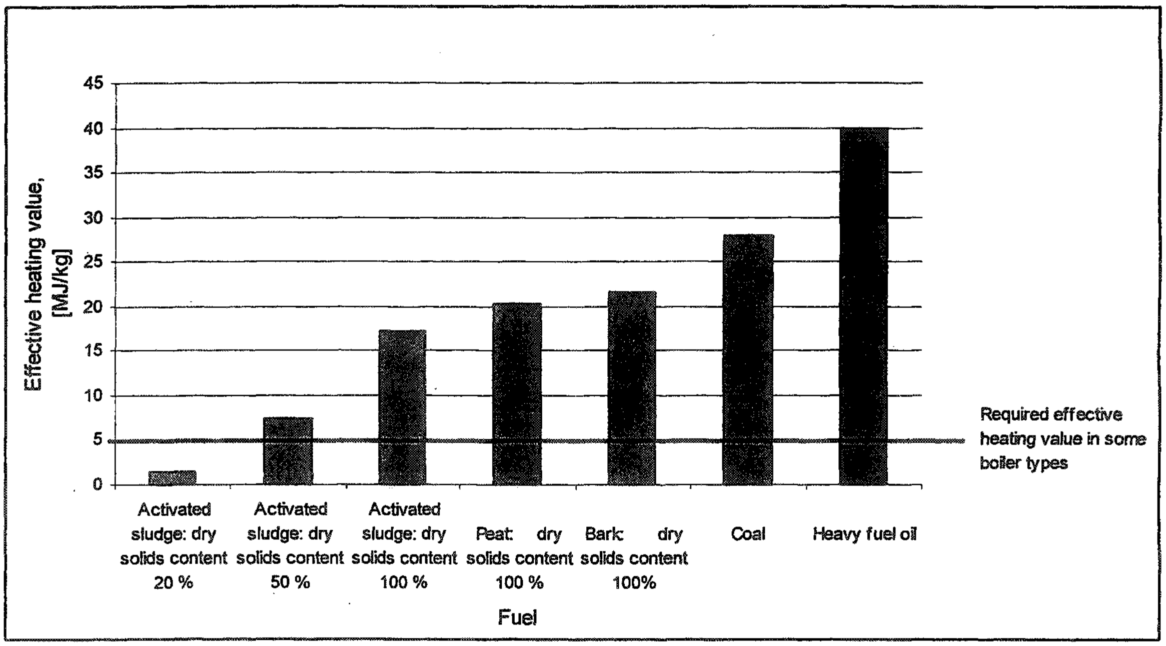

Figure 2. Effective Heating Value of Some Fuels

The new waste act in EU-countries requires the efficient use of waste products. Landfill costs will rise considerably in the near future because of stricter regulations on landfill areas. Construction and operation costs in new landfill areas can be from 20 \$ to 120 \$ per metric ton (Isännäinen 1994). At the moment these costs are normally much lower.

Table 1 shows the calculation of two options in sludge treatment. In the first option only conventional mechanical dewatering is used for activated sludge drying, while in the second, thermal dewatering is also used. The second option achieved a dry solids content of 50%. In the first option only half of the wet sludge flow can be burned and the other half must be dumped because of the limited burning capacity of the boiler, while in the second option the burning of thermally dried sludge is easier and the whole sludge flow can be utilized in heat production. Only ash must be dumped. If free excess energy is used for the drying process, the whole annual difference between cases can be invested in the thermal drying system of the activated sludge. Savings per evaporated water metric ton would be considerable.

Table 1. The Cost Estimation in Sludge Handling with Limited Boiler Capacity

Activated sludge formation in the effluent purification				
about 1.5 % of pulp production		9 000 tons dry solids/yr		
		1 000 kg dry solids/h		
Dry solids content of the sludge		20%	50%	
Sludge flow		5 000	2 000	kg/h
Effective energy content		2	8	MJ/kg
Mean power		2.8	4.5	MW
Value of the alternative fuel if the whole sludge flow can be burned:				
6.0	$/MWh	147000	237000	$/yr
Dumping costs if the whole sludge flow must be dumped:				
50	$/ton	-2250000	-900000	$/yr
When dry solids content is 20 % half of the sludge can be burned and half of it must be dumped because of limited boiler capacity				
	Price of alternative fuel		74000	$/yr
	Dumping costs		-1147000	$/yr
			-1073000	$/yr
When dry solids content is 50 % all of the sludge can be burned.				
	Price of alternative fuel		237000	$/yr
	Dumping costs of the ash		-44000	$/yr
			193000	$/yr
Difference between cases			1266000	$/yr
Difference per 1 metric ton dry solids			141	$/ton ds
Difference per evaporated water			48	$/m^3

The Results of the Experimental Tests

Evaporation under partial vacuum conditions makes it possible to utilize secondary heat in the evaporation process. According to preliminary experiments with a rotary evaporator, it is possible and relatively easy to dry activated sludge under such conditions. Experiments with evaporation equipment proved that it is relatively easy to dry activated sludge up to 50% dry solids content. Problems with sticking of the sludge were minor and cleaning of the equipment was easy when the evaporation temperature was between 50-60 °C. Thermal decomposition is minimal at temperatures under 100 °C. Because of easy cleaning acid washing agents were not needed. The normal washing agent based on tall oil was enough. The condensate that formed in the evaporation process was relatively clean and its reuse in other mill processes is possible.

Figure 3 shows the mass balance and temperature levels of a possible evaporation system. When the dry solids content of the egressing activated sludge is 50% the mass flow of the sludge is 2/5 of the incoming sludge flow. Because of low pressure in the evaporation process the temperature of the steam can be kept low.

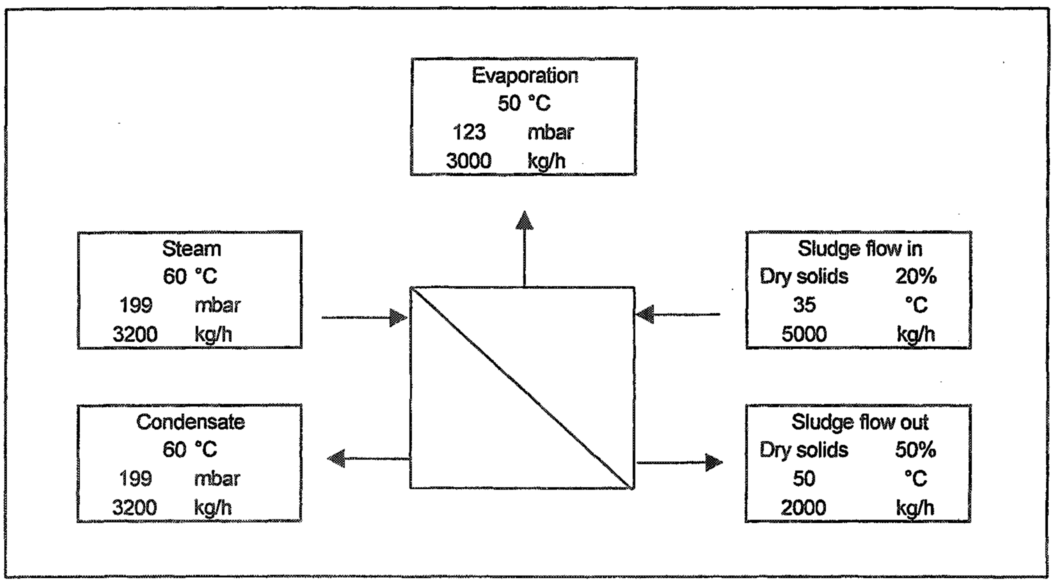

Figure 3. Mass Flows of the Evaporation Process When the Pulp Production in the Unit is 600,000 ADt/yr and Activated Sludge Formation is About 1.5% of the Pulp Production

The most significant result in respect of the evaporation process and secondary heat utilization was that the boiling point of the activated sludge did not rise when the dry solids content rose during the evaporation process. For example, for NaCl-water solution the boiling point rise at 30% dry solids content is about 7 °C (Jaakkola 1998). In Figure 4 we can see boiling point rise of some liquids that can be handled in evaporators. Because there is no boiling point rise for the activated sludge, the utilization of secondary heat is economical. The whole temperature difference in the heat exchanger can be used for the evaporation process.

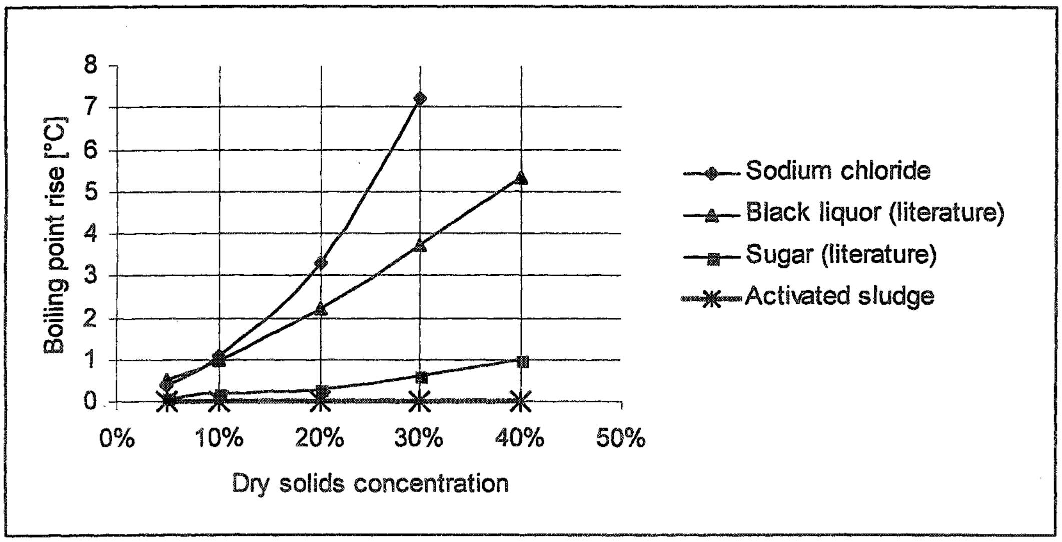

Figure 4. Boiling Point Rise as a Function of the Dry Solids Content of Some Substances

With our evaporation equipment, drying the activated sludge alone was easier than drying the mixture of activated sludge and sludge containing fibers. The sludge containing fibers stuck to the walls of the evaporation bottle causing heat transfer through the walls to decline rapidly. Cleaning the sludge containing fibers from the walls of the bottle was also more difficult. Adding oil to the process made the evaporation even slower and cleaning even more difficult.

It was estimated that activated sludge up to 15% dry solids content could be handled with pumps. After this limit the sludge formed a uniform block. When dry solids content was over 20% this uniform block disintegrated into pellet-like balls. When the dry solids content was over 25%, the surface of the pellets was so dry that it no longer stuck to the glass surface. The size of the balls was reduced when their water content was reduced during evaporation. Figure 5 shows concentrate from experimental tests of activated sludge evaporation under partial vacuum conditions.

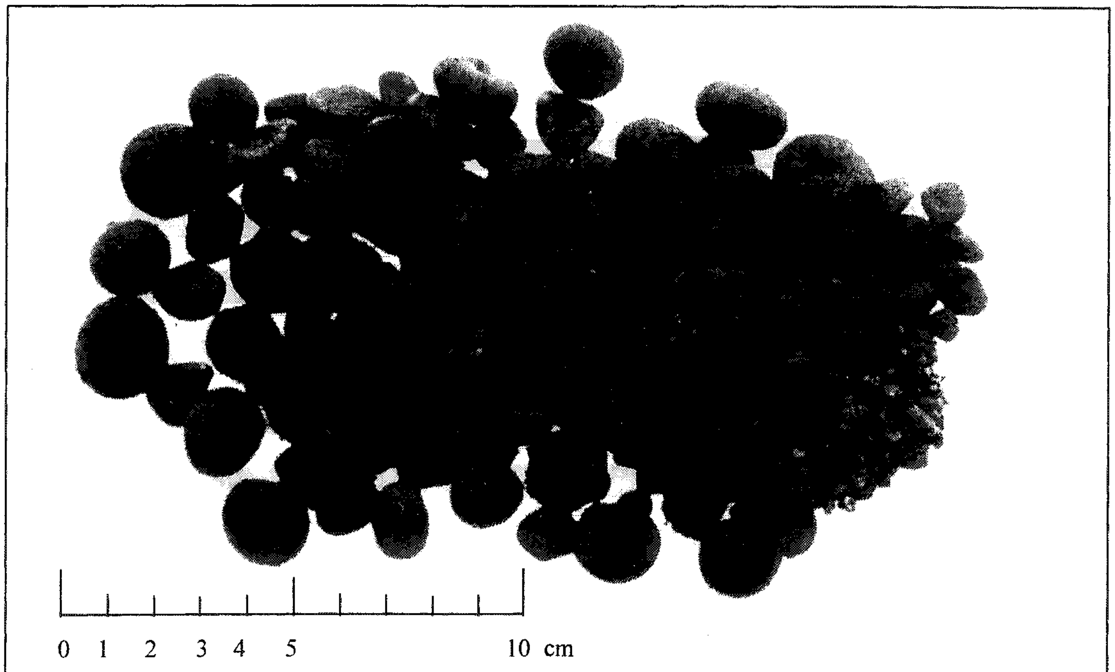

Figure 5. Concentrate from Experimental Tests of Activated Sludge Evaporation under Partial Vacuum Conditions, 120 mbar (abs.), Dry Solids Content about 50%

The desired dry solids concentration and equipment determine the properties of the output. Depending on the use of the dried sludge it is relatively easy to modify its properties by equipment and drying process modifications. For example, stirring the sludge and crushing the resulting pellets during the evaporation process achieves the desired size range and distribution. By recycling dried sludge it is possible to bypass the sticky phase. In our experiments the sticky phase was at 15-20% dry solids concentration. After the sticky phase the sludge can be handled by a conventional conveyor belt or a screw conveyor.

Estimations of Possibilities in Partial Vacuum Drying of Activated Sludge

The utilization of secondary heat at lower temperatures is possible if vacuum technology is applied. It would be relatively easy to utilize secondary heat flows that were at temperatures between 70-85 °C, if the evaporation temperature were about 50 °C and the pressure about 120 mbar. In many integrated forest industry factories, there is plenty of secondary heat in this temperature range. Figure 6 shows the boiling temperature of water as a function of pressure. In this figure we can see the pressure range suitable for an evaporation process utilizing low temperature secondary heat. By utilizing secondary energy the energy cost would remain low. In most cases the value of the secondary heat is very low or even negative.

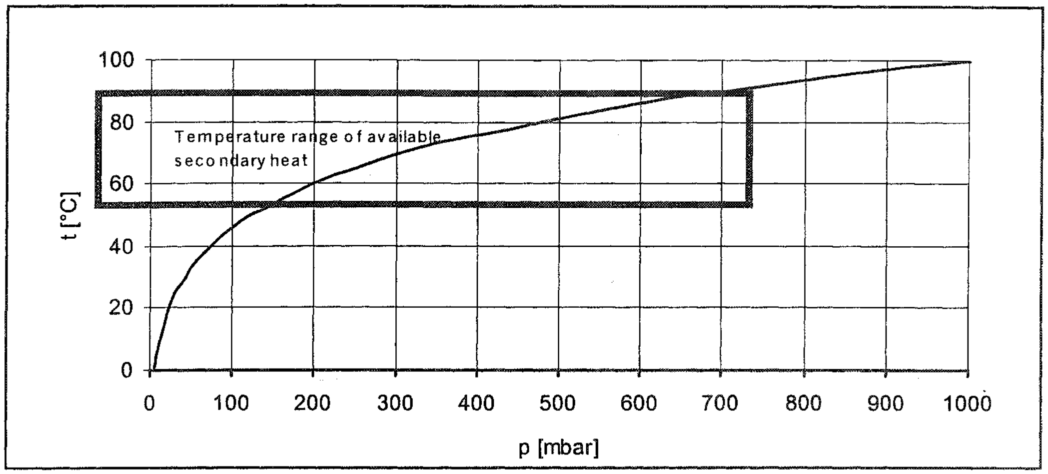

Figure 6. Boiling Point of the Water as a Function of the Pressure and Temperature Range of Available Secondary Heat Flows in Pulp and Paper Mills

Another advantage of vacuum technology and low temperatures is that the amount of vaporizing compounds is smaller at 50 °C than, for example, at 100 °C (Fagernäs 1997). This is why the condensate is also cleaner and more valuable in other processes than it would be in atmospheric evaporation. The components that vaporize at temperatures above 50 °C burn off in the boiler with the concentrate. Some of these components increase the effective heating value of the fuel.

The temperature range used in the evaporation process should be separately estimated in every case based on energy and equipment prices. If a continuous evaporation process with no disturbances is desired, occasional low-pressure steam utilization may be reasonable. Handling and storage of the sludge is easier if the dry solids content of the sludge is high enough, for example 50-80%. Moreover, the stability of the sludge is better when it is dry enough. Drying the sludge with secondary heat before the boiler reduces the use of primary heat to dry the sludge in the boiler during the combustion process. In this way more heat can be released for steam production.

The most economical way to dewater primary and secondary sludge is to treat them separately. Mechanical dewatering of the primary sludge is relatively easy and 50% dry solids concentration can be achieved. Mass flow of the sludge to be treated remains moderate if thermal drying is used only for the activated sludge. The mass flow of the dry solids in the activated sludge in modern pulp and paper mills producing 600 000 ADt/yr normally remains under 1000 kg/h.

If the evaporated steam can be utilized in the following evaporation stages at lower pressure, the heat required for the evaporation process is considerably lower than in a one-stage evaporation unit. In our calculations, it was found that when we use a three effect evaporator the energy content of the potential secondary heat flows is considerably higher than the heat required for the evaporation process. In a reference integrated pulp and paper mill under examination the heat content of hot water (80°C) flow is enough for activated sludge evaporation even with a 10% dry solids concentration at the beginning of the evaporation process. In Figure 7 we can see available excess secondary heat flow in a modern integrated pulp and paper mill in winter and summer time. In the same figure there are the results of calculations of the heat requirement of evaporation process involving activated sludge with two different incoming dry solids concentrations. In calculations, heat for evaporation is derived from 60°C steam that is derived from 80°C hot water with a steam separator.

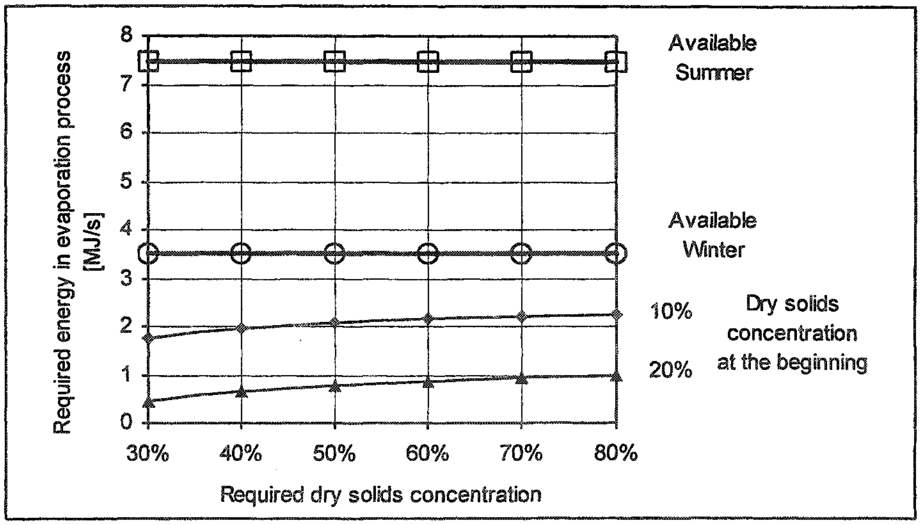

Figure 7. Theoretical Energy Consumption in Three Effect Evaporation, and Available Hot, 80°C, Water Flow in Winter and Summer in Reference Mill

References

Fagernäs Leena. 1997. "210T Characterization and further processing of effluent condensate and concentrate." In *VTT Symposium 170. SIHTI 2*. Energy and environmental technology. Yearbook of the Technology Program 1996. Project report. Espoo. Technical Research Centre of Finland. (In Finnish)

Jaakkola Heikki. 1998. "Concentration of the dryer feed with evaporation." In *Industrial drying processes*. AEL INSKO-seminar. Y329501. Helsinki. AEL-Centre for Technical Training (In Finnish)

Isännäinen Saara. 1994. "Utilization of waste matter in forest industry." In *Solid wastemanagement in forest industry*. AEL-INSKO-training. P904101/94 IV. Helsinki. AEL-Centre for Technical Training (In Finnish)