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Drying in Superheated Steam under Pressure

by

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ABSTRACT

Large dryers evaporating 10 to 70 t/h water requires a large energy supply, and if the drying takes place in air, it will give a severe atmospheric pollution. An example is the large dryers in the sugar industry for drying the pulp left over from the beet after the sugar has been extracted, The dried product is used for cattle feed. Traditionally this drying takes place in rotating drum driers, but the pollution and the large energy consumption was the background for the development of a new technology, where the drying takes place in superheated steam under pressure.
The development took 7 years starting with 2 years with fundamental research in the lab followed by 2 years of intensive work on a 10 m high pilot installation having a capability to evaporate 1 ton water per hour. Then a prototype with up to 12 t/h evaporation was built and the development continued on this in 3 years before the technology was ripe for industrial use.
Today there are built 24 industrial dryers with capacities up to 70 t/h water evaporation in one dryer. Further to beet pulp the technology is used for drying of bio fuels like wood chips, bark, and waste water sludge. The development is still going on for adapting the dryer to new products.
One large dryer (70 t/h evap) give the same reduction of CO_2 emission per day as a windmill park with 60 windmills of 2 MW.

INTRODUCTION

The traditional way to dry large quantities of particular materials is to dry in a rotation drum. See figure 1. In front of the drum there is a furnace, where gas, or another fuel, is burned. The hot exhaust gas is introduced into the rotating drum together with the material to be dried. At the other end of the drum the dried material is separated from the now cooled gas. This gas contains the main part the used energy in form of vapour mixed with air, dust and VOC. Only a part of the energy can be recovered and that at a low temperature, so it does not pay. And the pollution by dust and Volatile Organic Components is a problem.

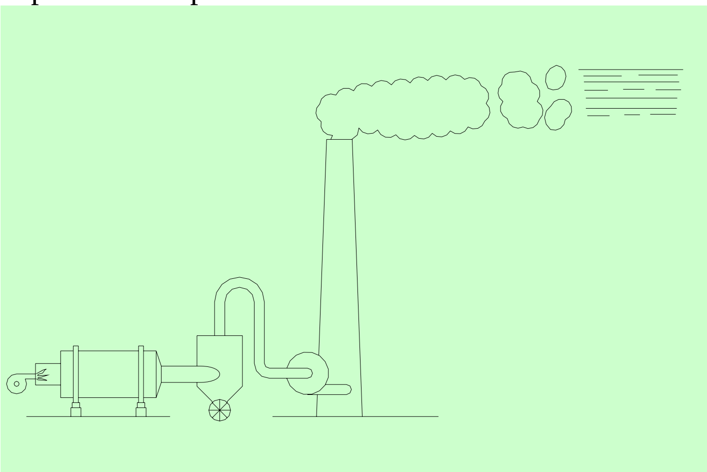


Figure 1. A rotating drum drier has a high energy use and a pollution problem.

If the drying could be done in a closed vessel as figure 2 it would have big advantages. The material should be fed continuously into the vessel and heat shall be added. The dried material is taken out, and the water that was in the material can be tapped from the vessel as a steam with the pressure that has been chosen to have in the vessel. Using this steam can lead to near 100% recovery of the used energy and all air pollution is avoided.

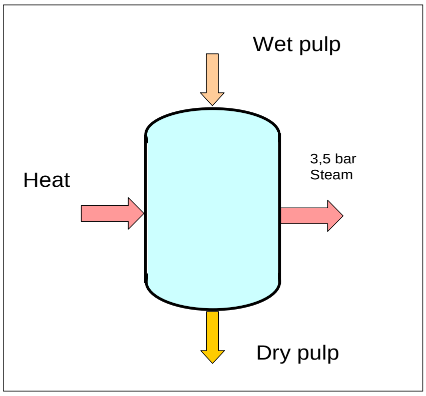


Figure 2.

The pulp, which is the left over from beets, when producing sugar, has traditionally been dried in drum driers. The demand for energy saving and pollution free drying was the reason to start a development a drier according to figure 2. The big question was to find out what should be inside the pressure vessel in order to make this to function in large scale. That was the start of a development back in 1981, when the oil price was high.

THE DEVELOPMENT

It started with fundamental research. Lab models were built for examination of what happened to the product in steam under pressure during the drying process. In a small chamber under 3 – 4 bar pressure super heated steam could be sent through pulp doing batch drying. It was difficult to do the batch drying in small scale due to condensation, when the batch was put in or taken out; but the test showed the first important thing that due to the Maillard-Reaction the material has taken colour after only 5 minutes, so the first conclusion was that the drying should be so fast that the material is out before 5 minutes has gone.

The heat could be transferred to the pulp particles either by 1) blowing superheated steam down through fixed bed of pulp particles. 2) Or up through the particles and form a fluid bed. 3) Or by contact directly to hot surfaces. Due to the Maillard-Reaction the possibility 1) could not be used, as the drying time is too long. Later findings showed that 3) - contact heat transfer – could only transfer a small part of the energy. See hereunder.

Beet pulp particles are far from uniform and uneven in size, and therefore not straight forward to fluidize. The fluidizing process was studied in different forms of fluid beds with jet effect and variation in percentage of open area in the distribution plate. Air was used as fluidization medium in those many different test units. In those fluid bed models there could also be inserted dummies for contact heating surfaces in form of tubes or plates in order to find out how many sq m heating area there could be placed in one m^3 fluid bed without plugging the fluid bed.

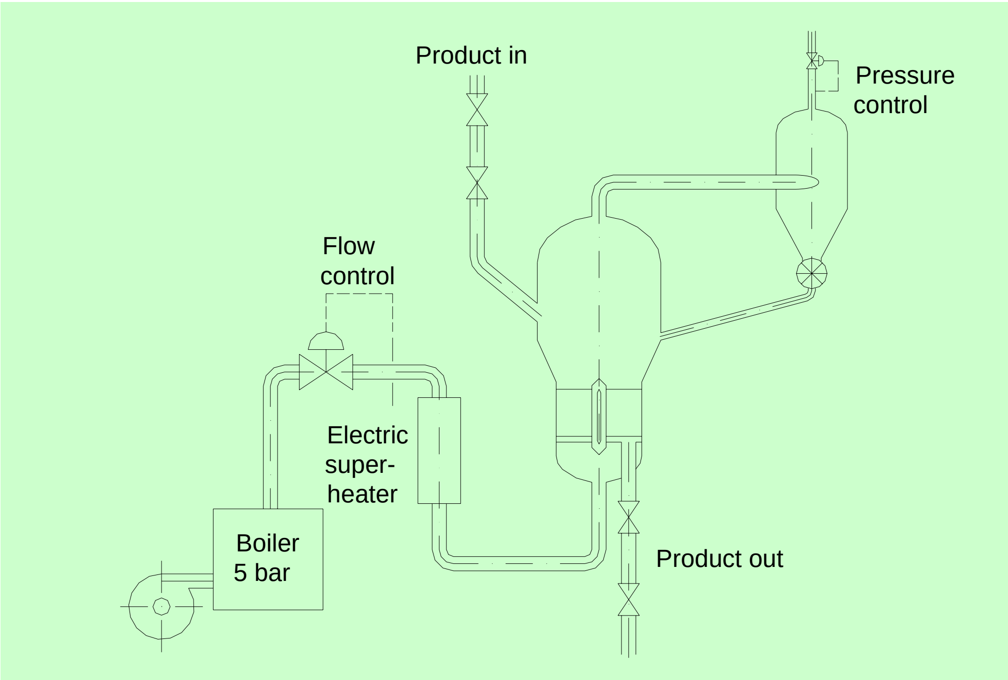


Figure 3. Small test drier with steam going one time through.

The next step was to make a fluid bed with steam with approx 0,5 m^2 distributor plate. Steam was supplied from a 4 bar boiler blown up through the fluid bed with a controlled flow and temperature. The pressure in the bed could be controlled as well. The steam went only once through the fluid bed drier, and after a cyclone it was vented to the free, so it was a highly energy consuming test dryer, but it could give data to be used for the next step. Hereunder data for how much heat it would be possible to transfer through the

inserted heating surfaces. This information combined with the information about how much area it would be possible to build in a fluid bed that is sized for max 5 minutes retentions time made it possible to calculate how much heat it would be possible to transfer through contact heating surfaces. As that was only approx. 10% of the needed heat, the 90% has to be transferred from the fluidization medium – the superheated steam. With practical possible f. ex. 210 ^{o}C at 3,5 bar steam the flow through the fluid bed can be calculated, and the conclusion was that the drier must have huge internal circulation of steam that must be cleaned for dust and reheated inside the pressure system including the dryer.
The tests showed also that the drying process was much faster under pressure than at atmospheric pressure. This is due to the higher density of the steam, which gives a better heat transfer. The drying in steam can be considered as a heat transfer that causes the water to be boiled out of the particles.
After 2 years with lab tests it was time to build a pilot plant. This was built up according to the diagram figure 4.

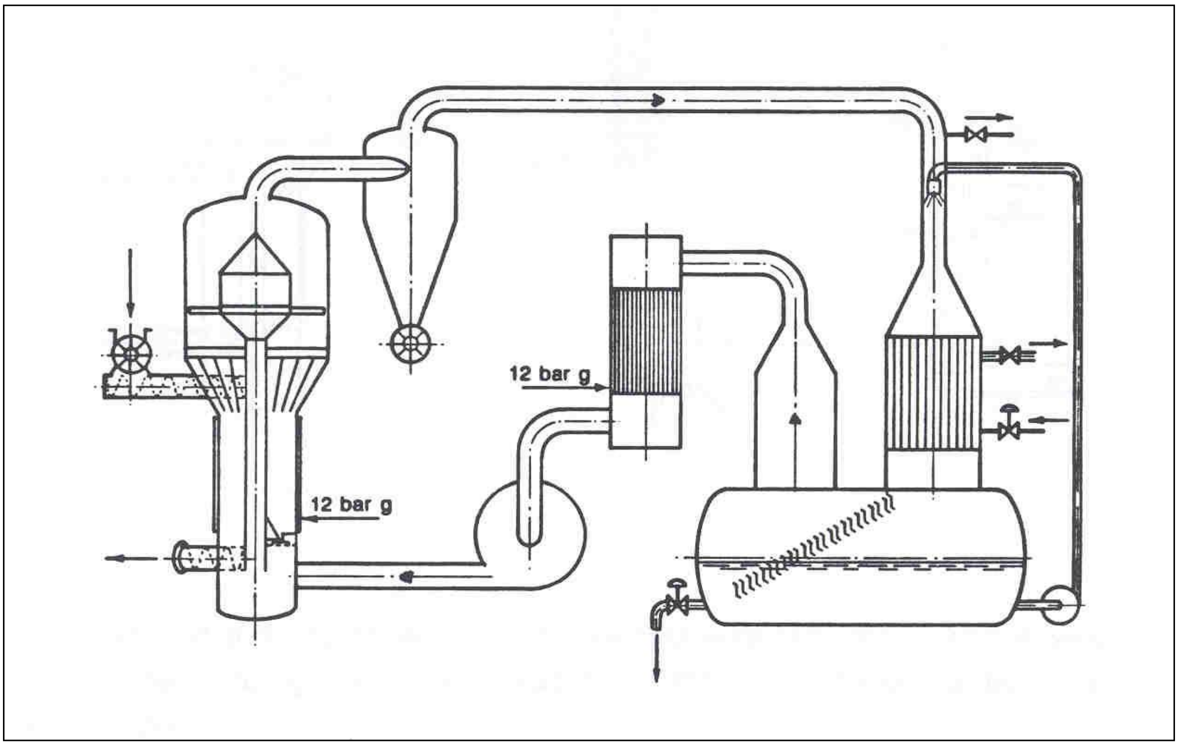


Figure 4. The pilot plant.

On figure 4 the pilot plant is seen. The drier is seen to the left with a rotary valve to bring the pulp particles into the pressurized dryer from where, it also passes out through a rotary valve. The drier was approx 7 m high and the evaporation capacity was around 1 t/h water evaporation. The circulated steam leaving the drier pass first a cyclone for dust separation then a scrubber, so the steam is rather clean before it is reheated in a shell and tube heater and then by a fan returned to the drier. The excess heat leaves the system through the heat exchanger under the scrubber in form of a clean steam.
A lot of data was collected from installation and there was worked on developing a good dust separation inside the top of the dryer. After that the dryer could be simplified to what is shown on figure 5.

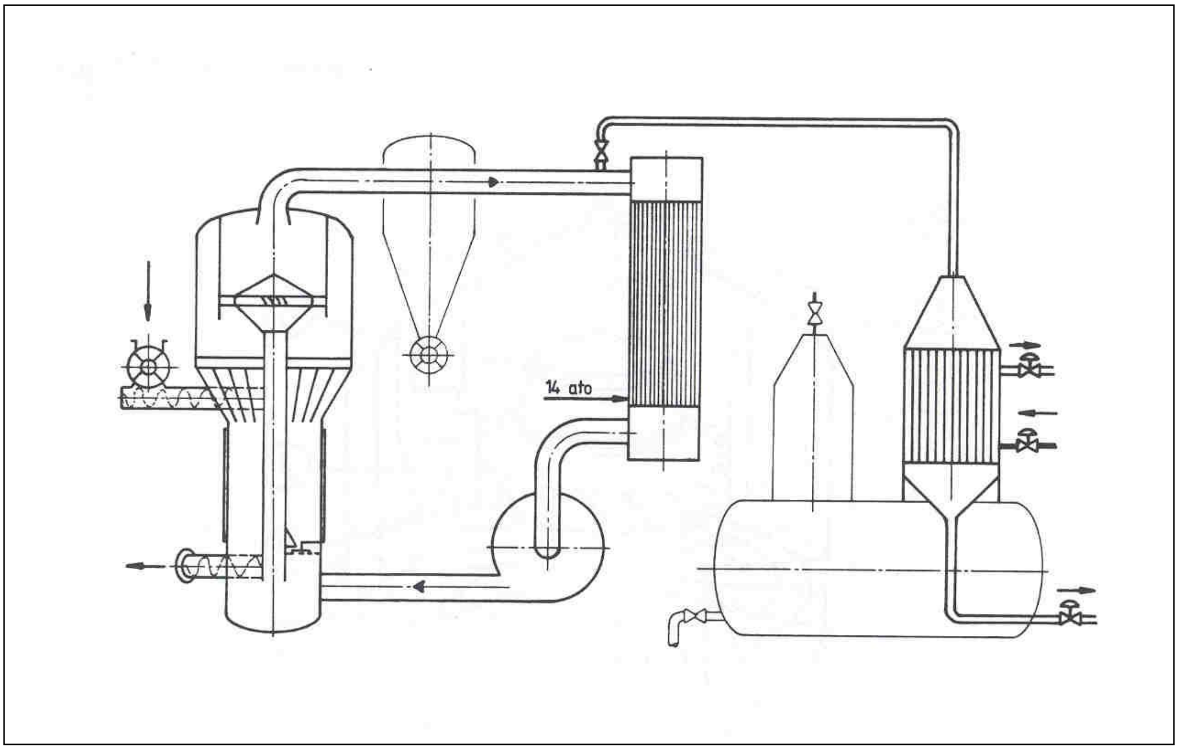


Figure 5. Simplified dryer pilot plant, with internal dust separation in the top of the dryer.

With the internal dust separation as on figure 5, it was possible to omit the dry and the wet dust separation. After collecting further data it was possible to design the prototype. The fan should be built into the bottom of the dryer and the heat exchanger in the centre. Thereby it would be possible to avoid the large external piping and a feasible large scale drier was possible. On the photo below figure 7 is shown placing of the large heat exchanger down through the top of the drier. The size is illustrated by the man on the top guiding the heater down.

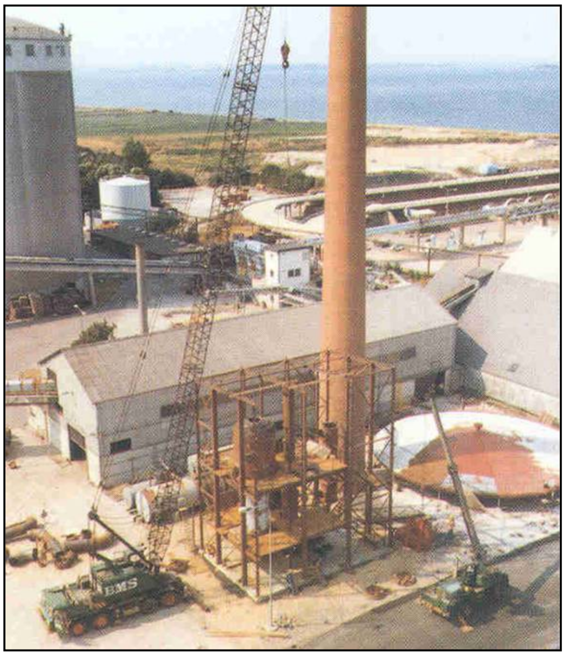


Figure 6. Pilot plant under erection.

Figure 7. Construction of the prototype.

The prototype dryer was able to work from the beginning, but not at the expected capacity of 6 t/h evaporation and there were many stops due to plugging of the dryer, material sticking inside the dryer etc. It took 3 years to get a good operation and up to 8 t/h water evaporation.
One of the things that took still many years to handle was the method to bring the pulp into the 3 to 4 bar steam atmosphere, and to get it out again. Different technologies was examined and tested, but it stayed with the rotary valves of a design similar to earlier used in paper industry for feeding wood chips into the pressurized cooker. Concerning the feeding into the dryer the problem was the heavy condensation on the pulp in the pockets that made it impossible to empty the pockets, and the remaining pulp in the pockets plugged the pressure release pipe and the feeding stopped. The problem was solved by mixing a little air with the steam, so the condensation was slowed down. The problem with the outlet rotary valve was wear. When the pockets with a mixture of steam and dried particles were released it created sound speed, which caused the wear problems. Also this problem is during the last 5 years solved.
The invention was published in 1987 and many visitors came to Stege in Danmark to see this installation and that led to the installation of a 3 times larger dryer (25 t/h evaporation) in Nangis in France. Later followed further development and dryers was sold for drying of beet pulp in West Europe, USA, and Japan. The largest dryer can evaporate 70 t/h water. The development is still going on today.

HOW IT WORKS

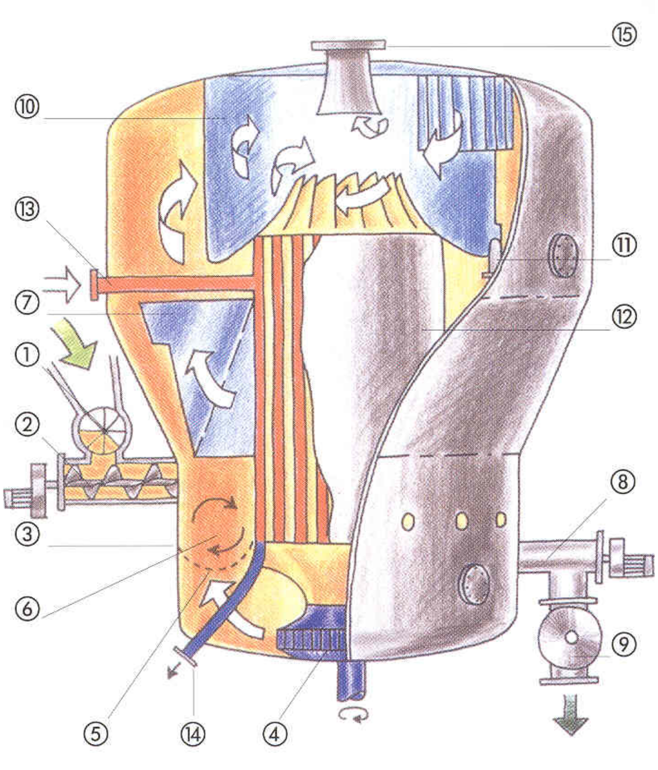
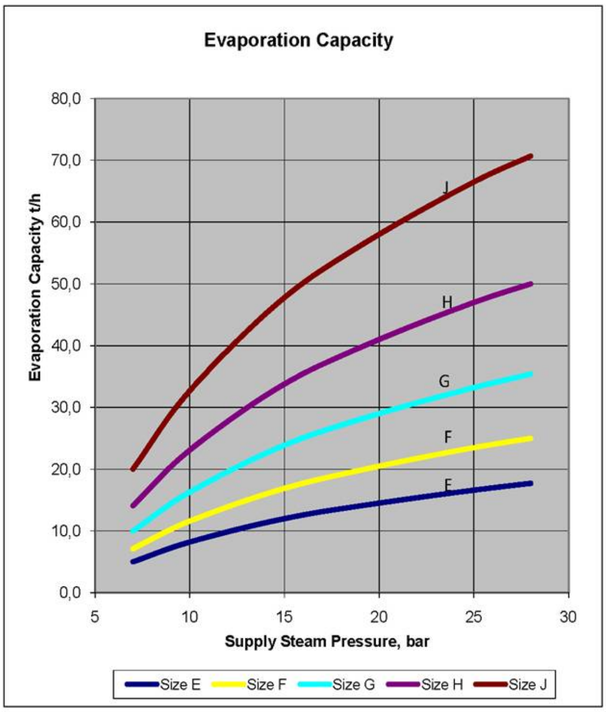


Figure 8. The steamdryer for beet pulp.

The drying takes place in a fluidized bed driven by superheated steam blown up through the pulp. It is all included in a pressure vessel with f. ex 4 bar also containing a dust separation, a heat exchanger, and a fan.
The pulp is fed through the rotary valve (1) to the screw (2), which brings the pulp into the pressure vessel (3) filled with superheated steam. The only moving part in the dryer is the

impeller (4) circulating this steam up through the perforated curved bottom (5) into a low ring shaped fluid bed (6) where the pulp is kept "fluid" swirling around as the arrows show. Guiding plates (not shown) make the pulp move forward in the ring. The lighter particles are blown up between the plates (7) radiating from the heat exchanger 12 outwards towards the conical vessel wall without reaching this. Due to the reduced velocity the particles fall onto the forward inclined plates, slide down on those and pass the gab between the plates and the conical vessel wall. In this way also the lighter particles passes forward around in the dryer and arrives to the discharge screw (8) and will pass the rotary valve (9).
The circulating steam arrives into the upper part of the dryer, where dust is separated in the main cyclone (10). The dust pass by means of an ejector out through the pipe (11) end goes out with the dried product.
The dust free steam goes down inside tubes in the heat exchanger (12) where it is reheated, as steam is supplied through the pipe (13). The supply steam is condensed and leaves the dryer through the pipe 14. By a higher supply steam pressure, a higher temperature of the circulating steam is achieved, and that will again increase the drying potential of the steam, when it again is blown up in the ring shaped fluid bed (6) by the fan (4). Therefore the capacity of the dryer will increase with increased supply pressure. This is illustrated on the curves figure 9 for the evaporation capacity of the different sizes of driers.



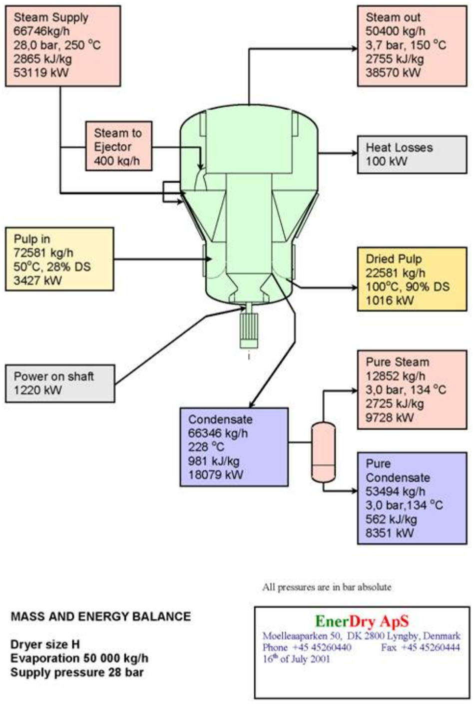


Figure 9. Capacity of dryers.

Figure 10. A balance for a dryer size H.

HOW DOES THE STEAMDRYER FIT INTO THE SUGAR FACTORY

The steamdryer is used for drying the beet pulp – the left over from the beets, when the sugar is taken out. It acts as a kind of evaporator placed in front of the juice evaporators. The steam leaving the dryer, which is the water evaporated out of the pulp, goes to the first step of the juice evaporator. Here the steam is used in a separate body as the condensate can not go back to the boilers, but it is good for e.g. freshwater for juice extraction. The clean condensate from the heat exchanger in the dryer shall go back to the boiler house.

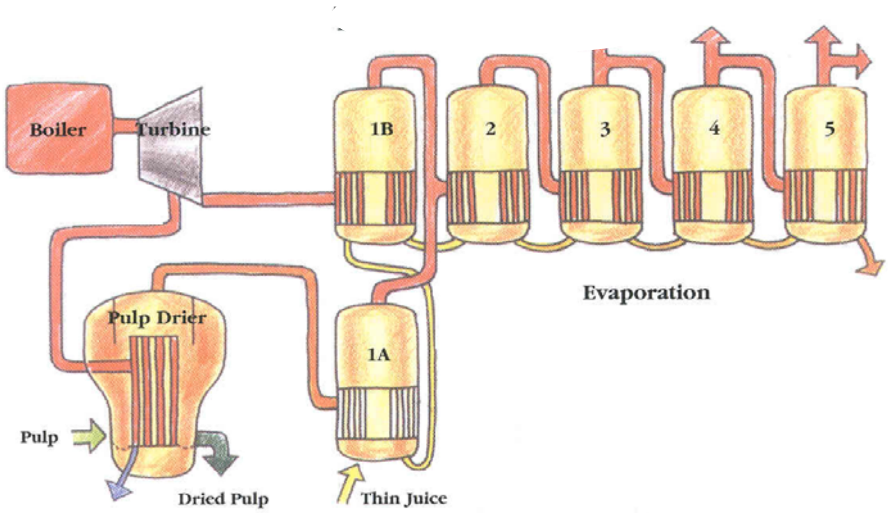
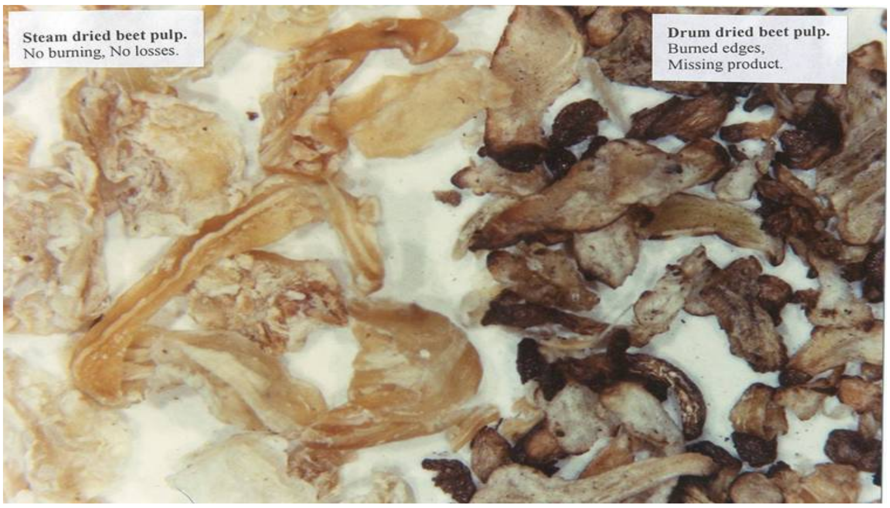


Figure11. Integration in a sugar factory.

As illustrated on figure 11 the drying will take place without air pollution, as the drying takes place in a closed vessel. And the drying does not consume energy, as all supplied energy is reused. There is therefore no increase of consumption of fuel in the boiler house due to the pulp drying. But the power production may go down. The energy in the lost power is not lost; the energy is still there. Only the possibility to convert it from heat in steam into power is lost.

PRODUCT QUALITY



By steamdrying there is no oxygen present, and therefore no burning of the product, as what happens in the classic drum dryers. On the photo the product to the left is steam dried. The drum dried is seen to the right. It is visible that the drum dried product has burned edges and some of the material is missing and the free

carbon can not be digested. The steam dried product is not burnt at all, but it has taken a slight yellow colour from beginning Maillard - Reaktion.
Under drying the wet particles gets the temperature that corresponds to the saturation temperature at the pressure. If the pressure is higher the particles are exposed to a higher temperature. This is often a disadvantage, that has to be accepted, but on the other hand the drying under pressure gives advantage as full energy recovery and no air pollution, and drying in steam means no oxidation.

PRODUCTS SUITABLE FOR PRESSURIZED DRYING.

The technology was developed for drying of beet pulp to produce cattle feed. There has been built 21 driers for this purpose. The pressurized drying can be used for other products. It is especially interesting for drying large bulk materials, when the alternative drying at is very energy consuming and polluting. The interesting range is from 5 to 100 t/h water evaporation. The technology can not be used for temperature sensitive product like many food products f. ex vegetables. Drying of fresh onion is also not possible as the cells will burst and the sliced onions will loose the structure and can therefore not form any kind of fluid bed.

Figure 13. Dryer for wood chips.

Wet fuels, hereunder wood chips, bark, sawdust, lignite, bagasse, etc should always be dried before being burned in the boilers. If burned wet, there will be used primary energy to evaporate the water from the fuel. The water vapour takes up a large volume in the combustion chamber and the gas cleaning system. The boiler capacity will go down, and it is not possible to get high temperature of the produced steam, whereby the potential for power production is reduced. By steamdrying of the fuel the energy for the dryer can be recovered. If wet fuel is burned, it is possible to recover energy from the exhaust gas leaving the boiler by condensing the water, but the recovered energy is at a temperature of 60 to 80 degree C, and the heat exchanger is difficult to keep clean. A power plant based on wet (50%) wood chips can produce 10 % more electricity out of the same fuel by steamdrying the fuel.

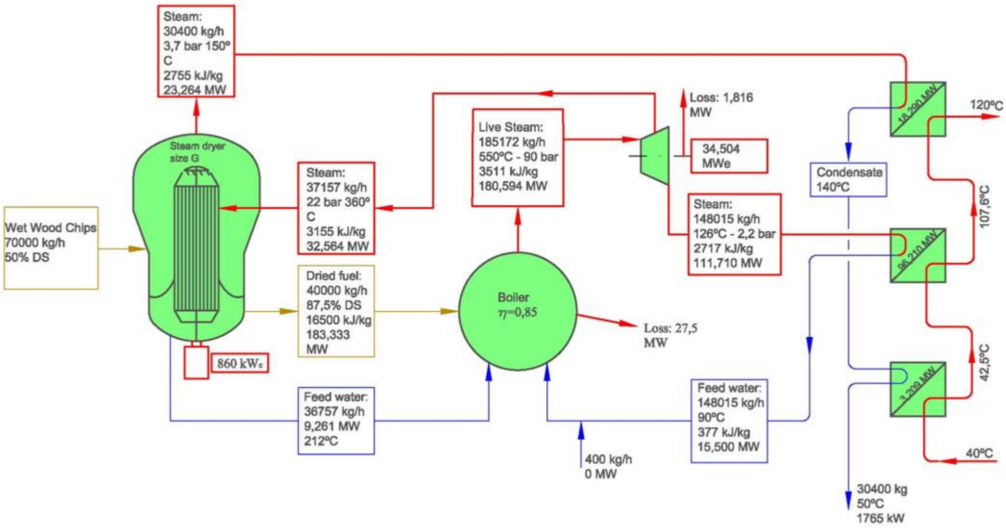


Figure 14. Power production and district heating based on wood chips.
Produced power: 34,5 $MW_{e,}$ Produced district heating. 117,4 MW

Another group of product is spent grain from ethanol plants, starch plants, breweries etc. The particles are small compared to beet pulp. The dryer must therefore be adapted to the product by less velocity of the fluidization medium – the circulating steam. Test drying has successfully been made on a full scale plant.

Sludge from waste water plant on a starch factory was dried. Sludge can not form a fluid bed, therefore it was necessary to back-mix dried product into the sludge coming from a belt press. The dried product was screened. The small fraction was used for back-mixing. The largest particles was slightly milled and also mixed back into the fresh pressed sludge. Thereby wet granules were made to feed the dryer. The final product was evenly sized dried granules as it was only the middle fraction from the screening.

Figure 15. Dried granulated waste water sludge.

STEAM COMPRESSION (HEAT PUMP DRYING)

When the dryer is used in industries having a need for 3 – 4 bar steam the dryer can easily be fit in, whereby full energy recovery can be obtained. In some cases there is no use for the steam leaving the dryer. The steam can then go to the atmosphere. Then there will only be an energy saving of approx 20 % compared to traditional drum drying. There will be no dust emission, but some odour from what might be evaporated out of the product. The advantages can not pay for the dryer, but it can be interesting to use steam compression.

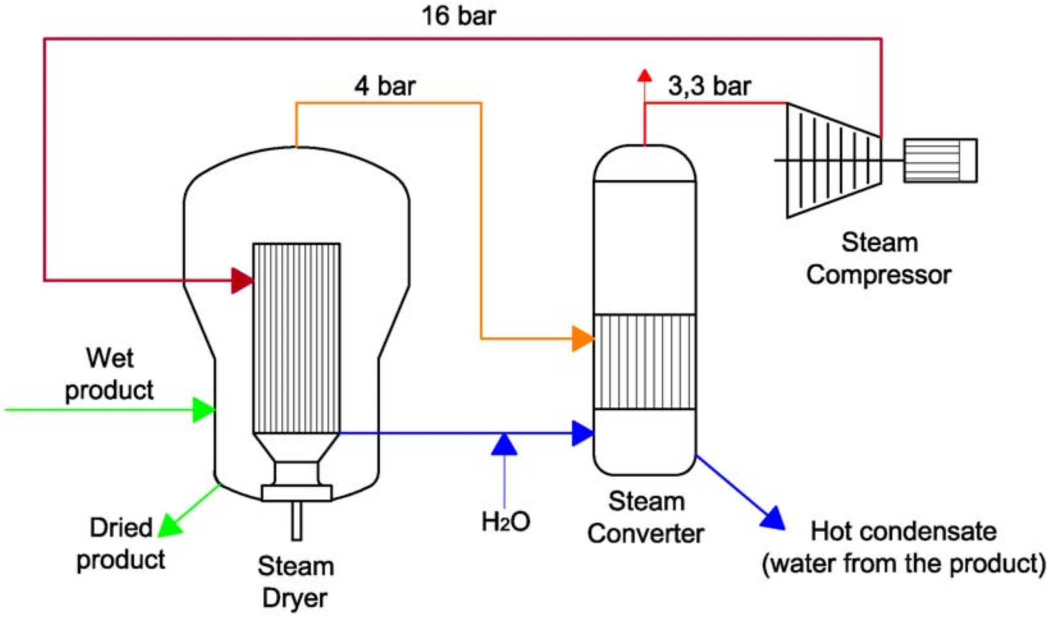


Figure 16. Steamdryer combined with steam compression.

The steam leaving the dryer is recompressed and used as energy supply for the dryer. It might be necessary to use clean steam in the compressor. If so, the steam from the dryer can then be converted in a heat exchanger of a design like an evaporator as used in many industries for concentration of juice, milk, etc. This way there can be saved 75 to 85% of the energy needed for the drying, but the remaining 15 to 25% must be supplied as mechanical power to drive the compressor. That might be by a large electric motor.

THE AMALGAMATED DRYING PROJECT IN IDAHO.

The Nampa sugar factory in Idaho slices 11000 t beets/day (metric) in approx 120 days. There is made 900 ton sugar per day the remaining sugar is stored as thick juice. The factory has also a molasses desugarization plant producing sugar and crystalline betaine from molasses. That gives also a need for concentration of raffinate. The factory has both 28 and 14 bar boilers. As many other American factories this factory has still a wide use of steam turbines in stead of the larger motors. The pulp is only pressed to 24% DS, so the need for drying is more than 70 t/h evaporation. It was decided to install a dryer size J with a guaranteed capacity of 71 t/h evaporation.

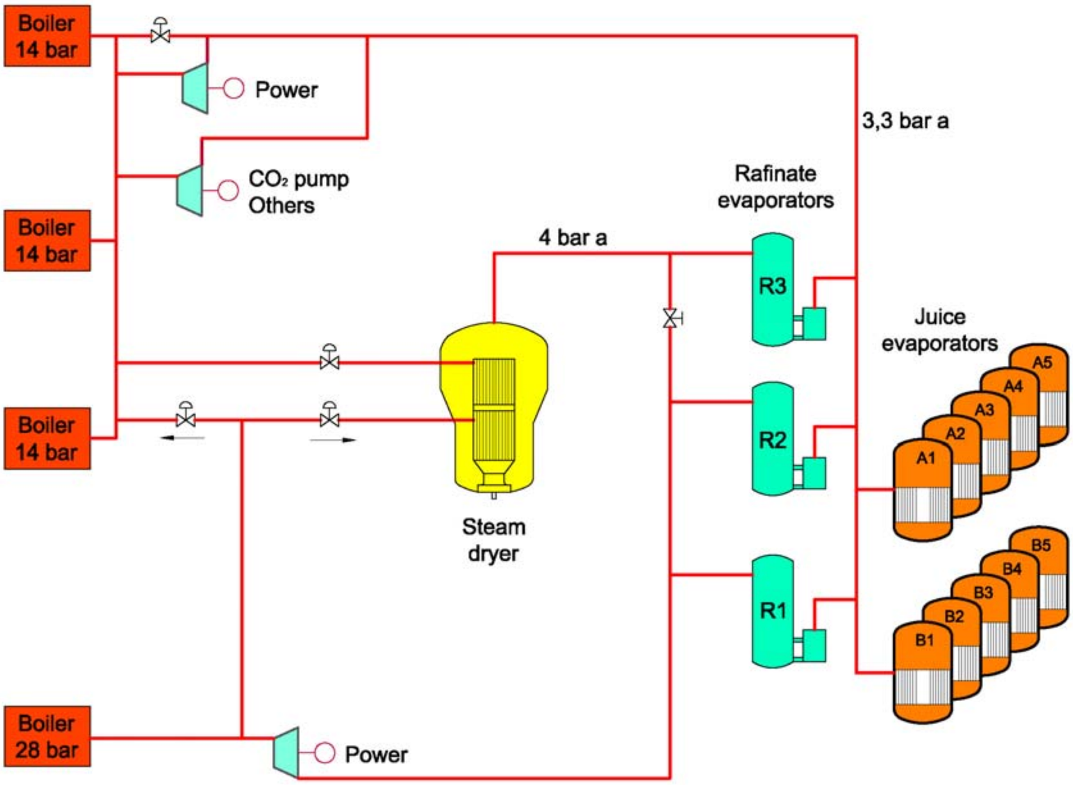


Figure 17. The steam system in Nampa Sugar Factory.

The main part of the power produced in the factory is produced by the 28 bar steam. In order to keep maximum power production it was decided to make the dryer with 2 super heaters - an upper one for the 14 bar steam and a lower one for the 28 bar steam. The steam system can be seen on figure 17 and 18. The flash steam from the 28 bar system goes to the 14 bar system, and this condensate does not yet go back to the boiler without flashing, but will do so in the future. This way it was possible to keep a good power production. The production was reduced by 4 MW the first year, but the reduction will only be 2.5 MW, when the last changes in the steam system are made. This reduction of power production shall be seen on the background of a saving of 62 MW as fuel out of which a modern power plant could make 30 MW electrical power.

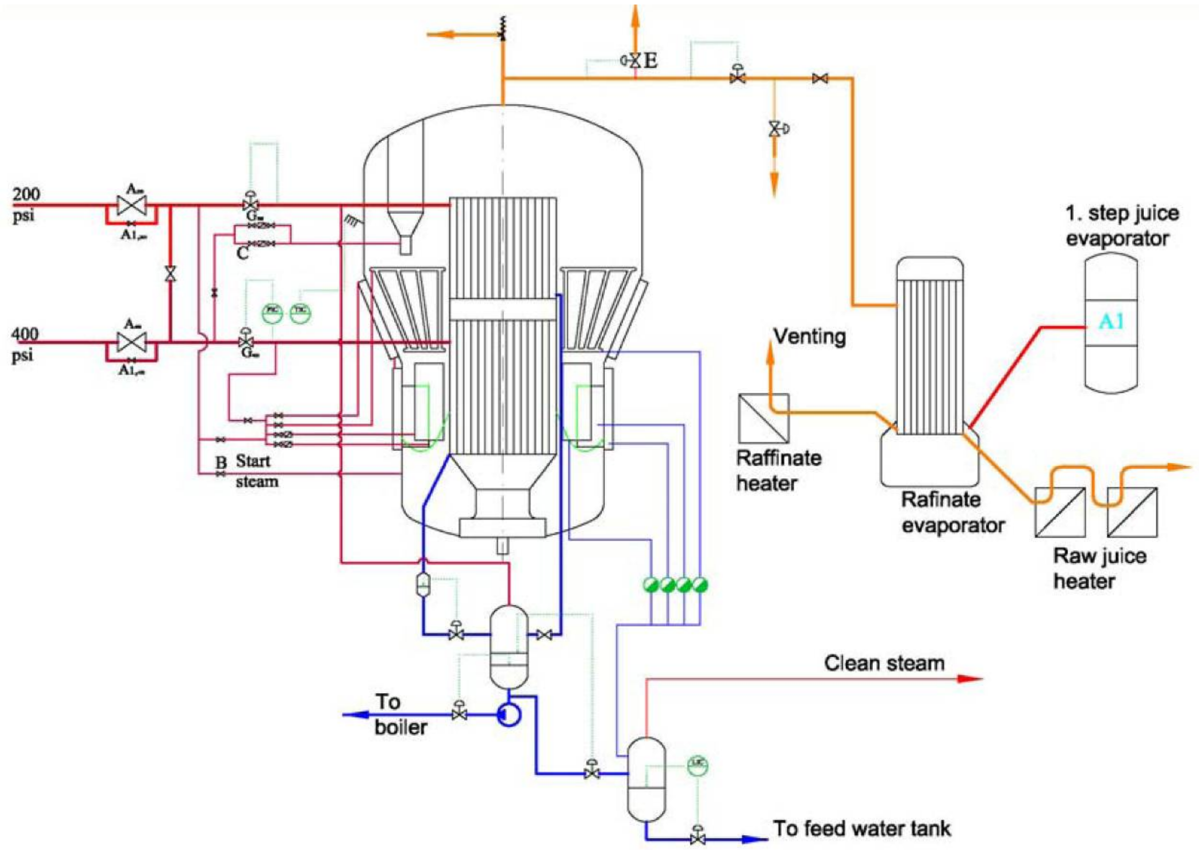


Figure 18. Steam and condensate around the drier.

Figure 19. The dryer in Nampa, Idaho under erection.

The Nampa dryer has a top diameter of 12,4 m. With this size J it has been possible to make the drier with the world largest drying capacity within this relatively small diameter. As mentioned before the drying capacity was guaranteed to be 71 t/h with only 400 psi (28 bar), but on the first week of operation the dryer went right up to 73 t/h evaporation using more then half of the steam from the 200 psi (14 bar) steam system, and the remaining steam supply came from 400 psi (28 bar) system. There was neither pulp enough nor steam available to go higher. From the temperatures measured in the dryer it is possible to calculate the max. capacity to be 83 t/h evaporation (metric). This high capacity is only possible by a high circulation of steam in the dryer, and that is only possible with the fluid bed design and dust separation patented by EnerDry.

The steamdryer in Nampa replaced 3 old coal fired drum driers from the 1950's. Major maintenance and a reduction of the environment impact were necessary. To fulfil the demands from the environment authorities it was decided have the steamdryer installed, which at the same time could give a daily saving on 200 t coal and an increased production of pellets as there would no more be burned product away. The project was an investment of 16,5 million $ That covers all costs for the total project inclusive building, conveyors, piping, electrical installations etc. The project was very well received by the public expressed as positive publicity in television and newspapers

ENERGY SAVING AND REDUCTION OF CO_2 EMISSION

1) The steamdryer in Nampa reduces the combustion of coal by 200 ton per day. Thereby the emission of CO_2 is reduced by approx. 600 ton per day. This can be compared to other investment for reducing the CO_2 emission like an ethanol factory or windmill park.
2) By using ethanol in the cars in stead of gasoline the net CO_2 emission is reduced as the growing of the corn or the wheat will absorb CO_2. But there is spend fuel for the tractors in the fields and for transportation as well as fuel for the steam boilers in the ethanol plant.
3) There can also be invested in windmills. For 12 mill € there can be installed 4 large windmills with the installed capacity of 4 x 2,0 MW. They will in average over a year produce 23% of the installed capacity. This power production reduce the production of power from coal fired power plants, and thereby reduce the CO_2 emission
Those three possibilities to reduce CO_2 emission are compared in the table below, where the CO_2 reduction also is related to the investment.

Nampa Steam dryer	**An ethanol factory on wheat**	**4 x 2 MW windmills**
200 t/day coal not fired **600 t/day** CO_2 emission avoided in 120 days per year.	Production: 8000 hl/day = 210000 gallon/day Avoided CO_2 emission: 1200 t/day CO_2 emission from cultivation -250 t/day CO_2 Steam boilers (487-789): - 600 t/day Net CO_2 reduction **350 t/day** In 340 days a year	Average production 23 % = 1,8 MW. A coal fired power plant will need 3,8 MW as fuel. Which corresponds to: 500 kg coal per hour, (27250 kJ/kg) Avoided CO_2 emission: 1500 kg/h = **36 t/day**
72 000 t CO_2 reduction per year.	119 000 t CO_2 reduction per year.	13 000 t CO_2 reduction per year.
No in-going product	2200 tons / day corn or wheat is used. 700 tons / day DDGS is produced.	No in-going product
Investment: 10,6 million €	Investment: 200 million €	Investment: 12 million €
6792 t yearly CO_2 reduction per million € invested	**595** t yearly CO_2 reduction per million € invested	**1083** t yearly CO_2 reduction per million € invested

The table shows the CO_2 reduction for the Nampa steamdryer, an ethanol factory, and windmills related to the investment.

CONCLUSION

- More than 90% energy saving can be obtained by steamdrying.
- Steamdrying gives no air pollution neither with dust nor VOC (odour).
- Up to 83 ton water evaporation in one drier.
- More then 20 driers are in operation. 6 large steam dryers in operation in USA.
- More reduction of CO_2 emission than by most other investments.

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