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# Industrial superheated steam drying

Research carried out and report written by TNO Environment, Energy and Process Innovation, Apeldoorn (NL)

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# Industrial superheated steam drying

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# Summary

Superheated steam drying is a drying technology where the drying takes place through direct contact between superheated steam and the product to be dried. Drying with superheated steam is an emergent technology with big potential advantages with respect to energy saving, emission reduction, fire and explosion prevention and product quality.
In order to promote the application of this relatively unknown drying technology, this study has been performed to map the industrial applications and experiences with superheated steam drying.

TNO, especially the Institute of Environment, Energy and Process Innovation, in Apeldoorn, The Netherlands, is well aware of the (im)possibilities of SHS drying and plays a role in the development and implementation of SHS dryers. The German FLT (Forschungsvereinigung für Luft- und Trocknungstechnik e.V. / Research association for drying technology) commissioned TNO to make an inventory of industrial applications and experiences with superheated steam drying in praxis.

This report describes the work performed, the interviewing in the field, chapter 3, and the information on the available steam drying equipment, chapter 4, and the experiences with superheated steam drying.

SHS drying is already quite widely applied in industry, with over 100 large-scale applications. There is a limited number of SHS dryers commercially available and the applications are limited to certain sectors and applications.

# Table of contents

# 1. Introduction

Superheated steam drying is a drying technology where the drying takes place through direct contact between superheated steam and the product to be dried. The superheated steam, SHS, delivers heat to the product and the moisture to be evaporated. It also forms the drying medium that takes away the steam that is produced by the evaporation of the water out of the product.
The SHS is recirculated and reheated in a closed loop, and only the amount of steam that corresponds to the amount of evaporated water, is removed from the closed loop. In this way the evaporated water comes available as (slightly superheated) steam whose energy can be recovered by condensation.
The closed loop implies that emissions coming from the drying product are not emitted to the environment, but will appear in the condensate.
The steam atmosphere and the different product temperatures that occur compared to drying with hot air might influence the product quality. The steam atmosphere is inert, no oxidation of the products and no fire or explosion risks exists.
The basic scheme of SHS drying in given in figure 1.

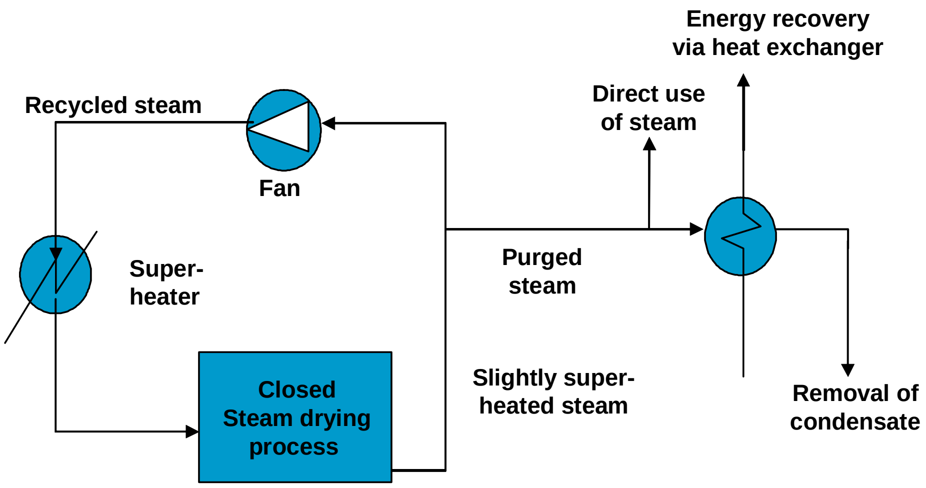



*Figure 1 Scheme of superheated steam drying.*

There are other drying technologies with partly the same advantages as SHS drying, especially that the evaporated water comes available as steam. This occurs at indirectly heated dryers, where no air is added or let in to the drying process. The evaporated water will, after some time necessary to vent the originally present air, come available as steam. These dryer types have the same advantages as SHS drying, like an inert steam atmosphere, the possibility of energy saving through heat recovery (depending on the pressure of the vented steam), no fire and explosion risk, etc.

Drying with superheated steam is an emergent technology with big potential advantages with respect to energy saving, emission reduction, fire and explosion prevention and product quality.
There is a lot of research about this subject and many articles are still published on this subject. Suitable SHS drying equipment is ready for industrial application or is under development. Quite many industrial superheated steam dryers have already been realised, and experience is building up.

The real break through in the industrial applications could be promoted by means of an overview of the **realised** applications and the **experiences** gained there.

TNO, especially the Institute of Environment, Energy and Process Innovation, in Apeldoorn, The Netherlands, is well aware of the (im)possibilities of SHS drying and plays a role in the development and implementation of SHS dryers.

This was the reason for the German FLT (Forschungsvereinigung für Luft- und Trocknungstechnik e.V. / Research association for drying technology) to ask TNO to make an inventory of industrial applications and experiences with superheated steam drying in praxis.

Far over 100 realised applications of SHS drying were found, mostly large-scale continuous dryers for bulk materials. The realised SHS drying installations originate from a limited number of manufacturers and the sectors where SHS drying is applied until now are limited as well, specifically the food and feed industry.
Besides these realised applications developments on SHS drying equipment are going on and some SHS dryers stands on the threshold of industrial application. They will shortly be discussed.

## 2. Goal of the project

The goal of this project is to communicate industrial experiences with superheated steam drying to companies and engineers that consider the application of superheated steam drying.
The principle of superheated steam drying is rather widely known and the potential benefits are well understood. The relative lack of realised installations and the unawareness of experiences with the installations applied at specific products however prevents the wider application of SHS drying.
By making the available knowledge accessible, the implementation will be promoted. The summary of this report will be published on the Internet and will be spread widely. The complete report is for sale by FLT at a moderate fee.

# 3. Persons and organisations contacted

Following the lists of the persons and organisations that have been contacted in the framework of this study. Mostly the interviewing was on the basis of a questionnaire. In order to collect as much as possible information on practical experiences with SHS drying equipment, telephonic and E-mail questioning has been done, on the basis of the questionnaire.

Persons and organisation contacted:

Builders of SHS equipment:
1. GEA Exergy AB, Gothenburg, Sweden; Daniel Frosterud, Ian Petterson; Exergy Steam Drying / Processor.
2. BMA Braunschweigische Maschinenbauanstalt Dr. Andreas Lehnberger / Dr. Lothar Krell, Sugar beat pulp dryers.
3. Carlille Stork Netherlands, Anton Bouman; former supplier of Exergy Dryers.
4. SWISS COMBI, Mr W. Kunz; EcoDry.
5. Fa. Eirich, Stefan Gerl, Eirich steam dryers.
6. Moenus (ex Babco-Therm,), Mr. F. Kunzmann; dyeing, fixation and drying in SHS.
7. CDS Group, Th. Stubbing, Graham Bird; airless dryers.
8. Hosokawa Nl, The Netherlands, David Hollestelle; flash steam dryer.

Industries applying SHS dryers:
1. Henkel, Austria, Dr. Wilfried Rähse; SHS dryer for detergents.
2. Vlisco, The Netherlands, Jan van Driel, Paul Oude Lenferink; SHS drying and tri removal.
3. AKZO, Kees van ’t Land, former drying expert from AKZO Nobel.
4. Avebe, The Netherlands, J. Zuur; SHS drying of fibres and proteins.
5. Bunge (former Cereol) Germany, Mr. R. van der Poel; drying and thermal treatment of feed components.
6. Techwood, The Netherlands, Mr. W. Derksen; SHS drying of wood fibres.

Institutes working on SHS drying:
1. ENSIA, France, J. Vasseur; SHS drying general.
2. TNO, The Netherlands, Wood drying, Mr. M. Riepen.
3. SINTEF, Norway, Prof. O. Alves-Filho, SHS drying general.
4. DK Teknik Energy & Environment, Mr. J.S. Nielsen, SHS drying general.
5. WKI Fraunhofer Institue for Wood Research, Dr. Andreas Hinsch, Dr. Timo Gruber, steam drying wood chips.
6. Techniprocess, France, Mr. Marc Sionneau, SHS drying general.

Universities working on SHS drying:

1. University of Singapore, Prof. Arun Mujumdar and Prof. Sakamon Devahastin.
2. University of Magdeburg, Germany, Dr. S. Heinrich, SHS drying general.
3. University of Karlsruhe, Prof. M. Kind, SHS drying general.
4. McGill University Montreal, Canada, Dr. Tadeusz Kudra, SHS drying general.
5. University of Lyon, France, Prof. J. Andrieu, SHS drying general.

In appendix C a complete list of people and organisations that were approached is given. The list presented here concerns people and organisations that gave the most relevant information.

## 3.1 Questionnaire

The following questionnaire was used as a guideline for the telephone conversations and for questioning by E-mail or on paper.

1. Products that are dried with superheated steam?
2. Industrial sector(s) applying superheated steam drying?
3. Throughput / evaporation capacity (ton/h / ton water evaporation/h)?
4. Drying system used, principle of dryer?
5. Drying system used, supplier of dryer?
6. Energy consumption / saving?
7. Emission reduction?
8. Operation experiences?
9. Reasons in favour or against superheated steam drying?
10. Other remarks or supplements?

The most relevant interviewing results are recorded in Appendix G.

Internet sites and literature also formed an important source of information and are used extensively. The results concerning specific SHS dryers can be found in Appendix D and E.

# 4. Types of SHS dryers

## 4.1 Working principles

The common quality of SHS drying is off course the fact that the drying takes place through direct contact from superheated steam with the product to be dried. The SHS delivers heat to the product and also forms the drying medium that takes away the steam that is produced by the evaporation of the water from the product; see figure 1.

With SHS drying the pressure of the steam is particularly important because it determines the reuse possibilities and the constant rate drying temperature; see Appendix A.
We can distinguish between:
- Atmospheric pressure, constant rate drying temperature 100 °C, excess steam comes available at 1 bar absolute, condensation temperature 100 °C.
- Pressure above atmospheric, constant rate drying temperature above 100 °C, especially used when energy recovery is essential.
- Pressure below atmospheric, constant rate drying temperature below 100 °C, especially used for temperature sensitive products in the food industry.

Most industrial SHS dryers operate at a pressure above atmospheric, some at atmospheric pressure.

SHS dryers, like all other dryers, can be categorised with respect to their working principle:
- Continuous operation
- Batch wise operation

Most industrial SHS dryers operate as continuous dryer, which is to be expected because especially bulk streams are dried.

More or less independent from the pressure a type of dryer is chosen, depending on the throughput and the handling of the products. The types most frequently used in SHS drying are:
- Pneumatic dryer
- Flash dryer
- Fluid bed dryer

Less common SHS dryers, some examples:
- Belt dryer
- Rotary drum dryer
- Spay dryer
- Mixing dryer

**Sealing of SHS dryers**
The sealing of the dryer and the in and output devices are critical with SHS drying, especially with over or under pressure. Rotating sluices and worms are most commonly used to take the products in and out of the dryer without substantial steam leakage.

**Insulation of SHS dryers**
Another strict requirement is the proper insulation of the dryer and the connecting ductwork. Al parts that come into contact with steam, even if it is superheated, have to stay above the condensation temperature of the steam at the prevalent pressure. Preheating of the equipment at the upstart and proper insulation must prevent condensation.

**Steam reuse of SHS dryers**
One of the big advantages of SHS drying is the energy saving by the recovery of the condensation heat available in the excess steam. The applicability and the 'value' of the steam depends to a great extend on other heat demanding processes in a factory. The pressure of the excess steam is the same as the pressure in the drying process. If the pressure in the drying process is the same as the pressure of the steam system of the factory the excess steam can directly be used. If fouling is a problem reboiling can be applied. Atmospheric steam from an atmospheric SHS dryer will mostly be used for heating up water by direct or indirect heat transfer.
If no suitable heat consumer is available, the energy saving potential is much lower, accounting only for the absence of hot air that is vented to the environment in other dryers.

## 4.2 Available SHS equipment

The following SHS dryers are on the market and applied in praxis.
The basic working principle and schematic drawings are described here. In Appendix D and E more extensive information, pictures, brochures and Internet addresses are given.

**1. GEA Exergy Barr-Rosin dryer**
The GEA exergy dryer was originally developed at Chalmers University in Sweden and commercialised by Svensk Exergiteknik who placed many installations. Since 1989 Stork Friesland bv from The Netherlands took over the rights and developed the system further especially for sewage sludges. In the beginning of the nineties it was made over to NIRO, now part of the GEA/Barr-Rosin Company. The part of the GEA/Barr-Rosin Company who is delivering the so-called Exergy steam dryer / processor, is located in Gothenburg, Sweden.

The working principle is a closed loop pneumatic conveying dryer, where pressurised SHS is circulated by a fan. External heaters around the steam transporting pipes superheat the circulating steam. The solids or slurries are fed into the pneumatic conveying system through a pressure tight rotary valve and/or worm. The dried product is separated from the circulating SHS in a cyclone and taken out through a pressure tight rotary valve. See figure 2 below.

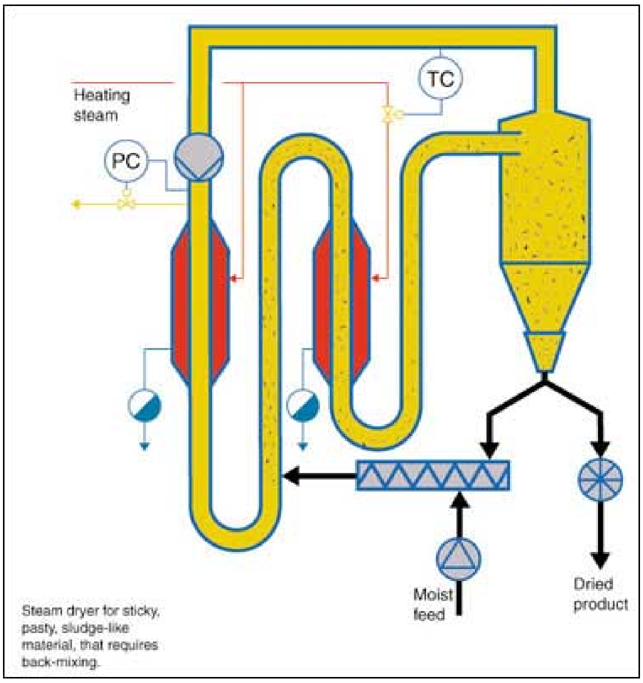



*Figure 2 Principal scheme of a GEA Exergy Barr-Rosin dryer.*

From the Exergy dryer about 25 installations are realised in praxis.

**2. BMA / NIRO fluid bed SHS dryer**

The BMA / NIRO fluid bed SHS dryer is developed in Denmark for the sugar industry by De Danske Sukkerfabrikken, DDS, and first placed at the Stege Sugar Factory in Denmark. Later on the equipment was commercialised for beet pulp drying by NIRO. The concept is now brought to the market by BMA AG. Since September 1990 14 dryers, with capacities varying from 25 to 50 tons of water evaporation per hour, are installed, only for sugar beet pulp drying.

The working principle is a pressurised fluidised bed dryer, with indirect heating with high-pressure steam. The dryer consists of a large vertical cylinder with vertical segments. The product is fluidised and taken up in a segment by the SHS and falls down in the next segment. In this way all 14 segments are passed through until the product is dry and leaves the dryer. The pressurised SHS is circulated by a fan and heated by an internal heat exchanger, heated with high-pressure steam. Input and output are realised by means of screws. The pressure inside the dryer is approximately 3 bars. The residence time of the sugar beet pulp is approximately 8 minutes.

These kind of systems can also be delivered or modified by EnerDry ApS, the company of Mr. Arne Sloth Jensen.

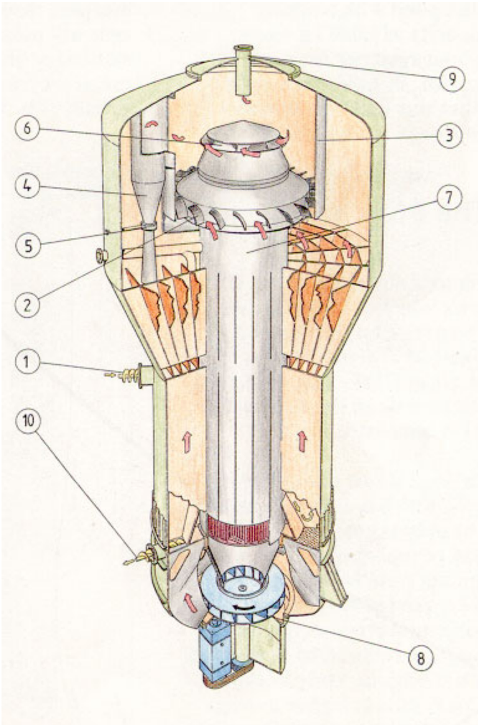



*Figure 3* *Internal structure of a BMA / NIRO fluid bed SHS dryer and picture of an installed dryer.*

## 3. Eirich mixing SHS dryer

The German firm Maschinenfabrik Gustav Eirich GmbH & Co KG, delivers a batch wise operating SHS dryer, Evactherm. In a rotating pan the product is intensively mixed and other treatments like mixing, granulation etc can be realised simultaneously. The drying process and the recirculating steam are operated with under pressure.

Applications are sludges, with recoverable heavy metals, desulphurisation sludges, ferrites, brake lining, coating sludges, catalysts, pigments, wash powder additives, etc. Some 12 SHS dryers are in operation now.

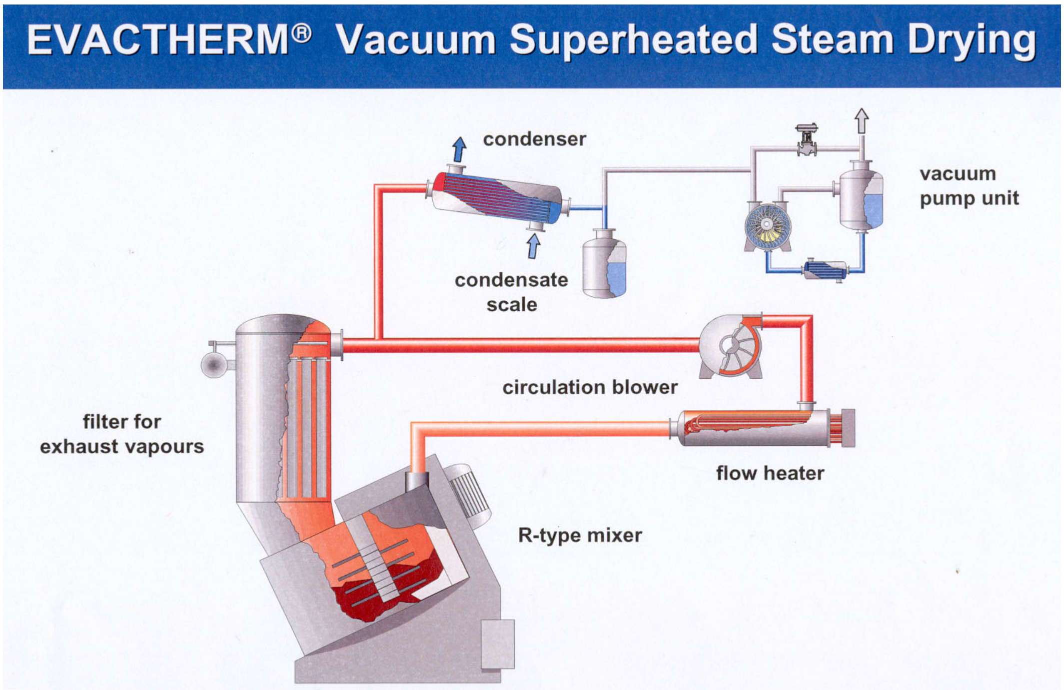



*Figure 4 Principal scheme of a SHS Evactherm dryer.*

## 4. Swiss Combi Ecodry

This Swiss company produces a SHS dryer for drying of wood fibres. It is a rotary drum dryer with recirculating SHS. The dryer was developed as a spin off from the Fraunhofer Institute of Wood Research, WKI.

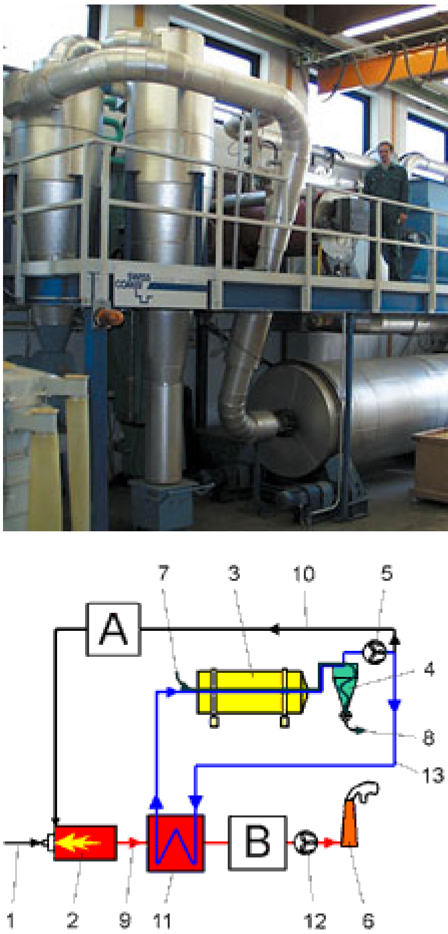



*Figure 5 Principal scheme of a Swiss Combi Ecodry.*

*1. Burner (gas, oil, dust)*
*2. Kiln*
*3. Drying drum*
*4. Cyclone*
*5. Circulation blower*
*6. Exhaust stack*
*7. Wet product*
*8. Dry product*
*9. Hot gases*
*10. Vapour recycling*
*11. Heat exchanger*
*12. Flue gas extractor fan*
*13. Vapour loop*

The pilot plant at the WKI, with a steam power of 100 kilowatts, dries 200 kilograms of wood chips per hour in a rotary tube furnace. The two cyclones (left) continuously separate wood chips from the steam flow.
Some 60 dryers from this type have been installed since 1989 and capacities are up to 25 ton/h. As the main advantages, especially with wood drying, the emission reduction and the product quality are reported. The steam takes up all emissions originating from the product. After condensation of the excess steam, only a small

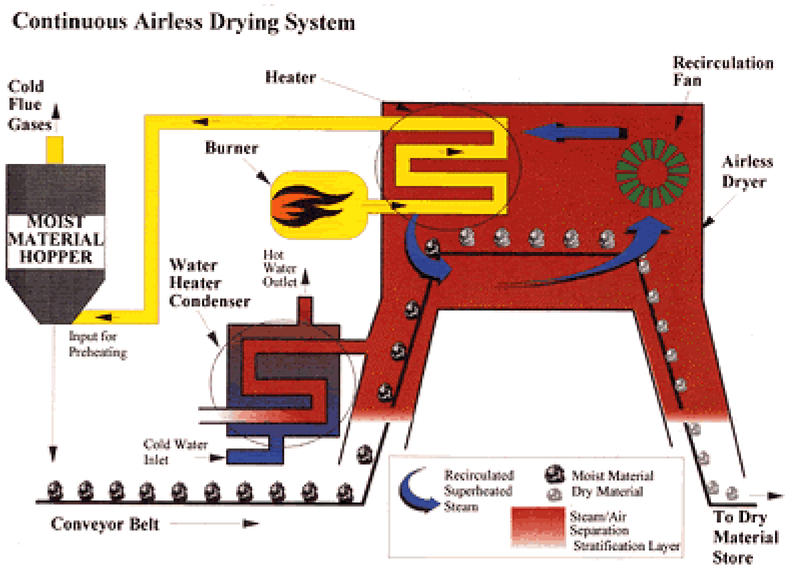
amount of non condensables is left, that can easily be after burned, for example in a boiler.

## 5. Moenus (former Babcock)

Moenus Artos Textilmaschinen GmbH from Germany delivers textile dryers for textile sheets with SHS jets impinging onto the surface. The sealing of the SHS drying section is realised by stratification. The SHS, that has a lower specific weight than air, is contained in a steam cavity that is closed at the top but open at the bottom. The textile web can enter and leave the closed steam cavity from below without loss of steam. Until now 2 SHS dryers have been delivered and first experiences are building up. One of the main advantages is the fact that drying is combined with fixation of reactive dyeing on the textile in an atmospheric steam atmosphere.

## 6. CDS airless dryer

The airless drying technology was developed and patented by Thomas J. Stubbing from the UK. He founded heat-win ltd. and established cooperation with Ceramic Drying Systems Ltd., who is delivering is airless dryers to the ceramic industry worldwide. The process has also been demonstrated with the tumble-drying of laundry, and with other materials such as paper industry sludges.
The airless drying principle is that the drying starts in air. To replace the air initially contained in an airless dryer, the air is recirculated over an indirect heater, through or around a moist product. This heats the air and the dryer's internal components to above 100 °C, while the moist product's surface temperature rises towards 100 °C. After a short while the drying atmosphere completely consists of SHS.
The SHS drying chamber is closed at the top and open at the bottom. The products go in and out from the bottom side. Thus the stratification of the light steam is used for sealing the steam atmosphere from the surroundings.




## 7. Henkel SHS dryer for washing powder

This concerns an individually designed and built SHS dryer for washing powders, with an evaporation capacity of 4 – 6 tons/h. It is an atmospheric spray tower with a SHS temperature of 120 - 350 °C. The main reason for this development is the emission reduction, the only way to get a license to operate in a densely populated area. Also energy saving, safety aspects, explosion and fire risk, are additional arguments in favour of the SHS drying technology.

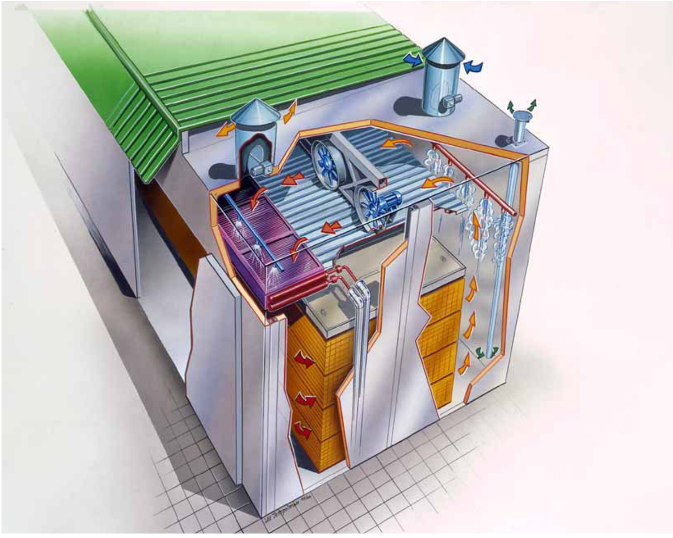
## 8. Hosokawa pneumatic flash SHS dryer

This dryer is based on a commercially available pneumatic flash dryer operated with air or nitrogen. For the steam drying application a recirculating steam loop is added. The equipment is especially suitable for pastes and slurries that are dried to powder. The sludges are fed onto a grinding rotor and the dry particles leave the dryer through a classifier.

Many products have been dried in SHS at pilot scale, industrial applications are expected soon.

**9. HB Group, Drying chambers for timber**

This concerns batch wise drying of wood in SHS drying rooms where both temperature and humidity are controlled during the drying process. During a part of the drying cycle the dryer works with SHS. Main advantages lay in the faster drying, halving of the drying time, energy saving and better product quality.



## 4.3 SHS equipment under development

**1. CDS / Stramproy airless dryer**

The Dutch company Stramproy Projects & Systems in cooperation with Ceramic Drying Systems Ltd. (CDS) from the UK has developed a Louvered rotary dryer, based on the airless drying principle towards pilot scale. Pilot scale testing has been performed for SHS drying of wood chips, biomass and sludges.

**2. Techni Process Fr. SHS spray dryer**

The pilot SHS spray dryer, with a 50 kg/h evaporation rate at 700 °C, is based on research from ENSIA in France. Further development is necessary to come to industrial equipment and demonstrations.

**3. Airless laundry dryers**

The airless drying concept, atmospheric SHS with indirect heating, can well be applied to laundry drying. The Dutch firm Landuwasco, specialised in laundry equipment, is developing the concept.

# 5. Applicability of superheated steam drying

## 5.1 Industrial sectors and products

| Industrial sector: | Products: |
|---|---|
| Food industry – sugar | Sugar beet pulp, dietary fibre from sugar beet |
| Feed industry – base materials | Hog fuel, Corn fibres, Protein containing base materials (soy beans, rape seed, sunflower seed, soy meal, Okara, etc.) |
| Food industry | Shrimps, Pork, Bamboo shoot, Paddy / rice, Herbs, Cacao beans, Corn gluten, Tobacco (drying, expansion) |
| Food industry - starch | Starch, gets gelatinised, Wheat flour, Distillers grain |
| Food industry - meat | Pork, Bone meal |
| Biomass (for electricity generation) | Sawdust, Wood fibre, Pulverised coal, Wood chips, Wood pulp, Pruce and Birch bark, milled peat, Peat for briquettes |
| Chemical industry | Washing powder, pigments, Potassium salt, Powdery chemicals, Catalysts, Colouring agents |
| Laundry industry | Laundry |
| Paper & Pulp | Paper, Fibre sludge from waste water treatment |
| Textile | (Coated) Textile |
| Waste materials | Industrial wastes, filter cakes, sludges from water purification, municipal sludge, |
| Vegetables & Fruits | Vegetables |
| Dairy industry | Milk powder |
| Potato | Potato products, Fries (pre-drying) |
| Building materials | Wood, Lime mud (before calcination), mineral wool, fibres |

## 5.2 Advantages in praxis

### 1. Recovery of energy

As the evaporated water comes available as slightly superheated steam, its energy content can easily be recovered at a relatively high temperature level by condensation of the steam. This temperature level is depending on the steam pressure. Atmospheric SHS dryers will generate atmospheric steam, whose energy will come available after condensation at 100°C. Higher pressures lead to higher temperatures, lower pressures to lower temperatures. The net energy input of an SHS dryer is only for the ventilation of the SHS, to overcome pressure losses, and to compensate for steam losses and transmission to the surroundings. Net energy saving potential of 50 to 75%, compared to other drying technologies, is well possible in the industrial praxis.

**2. Emission reduction**
Drying processes often are sources of emissions like odours, dust, white plume, hazardous components, etc. These components are introduced to the surroundings by the drying air that also removes the evaporated water. In many cases expensive measures like after burners, scrubbers or filters are necessary to prevent the emissions. With SHS drying the majority of the emissions will appear in the steam condensate. Only a small stream of non-condensables will remain, that might for example be after burned in an existing burner.

**3. Higher drying rates, drying time reduction**
The higher specific heat of steam compared to air, and the possibility to dry at higher temperatures, because no oxidation can occur, might increase the drying rate and thus reduce the drying time and the dryer volume. At some cases, for example at timber drying, a 50% reduction of the drying time is possible.

**4. Recovery of solvents, volatiles, etc.**
Solvents, volatiles or other components originating from the product, appear in the steam condensate. The can often be recovered by separation or distillation. An example is terpines from wood drying.

**5. Fire and explosion risk elimination**
The guaranteed absence of air and oxygen in a SHS dryer eliminates fire and explosion risk. With reference to the ATEX regulations for (drying) equipment, this appears to be a big advantage. With the start up and shut down of SHS drying process, risks have to be considered.

**6. Combination of processes**
SHS drying implies that the product temperature at the constant drying rate phase is higher compared to drying with hot air. Besides that the atmosphere is oxygen free. For food stuffs sterilisation and/or blanching will occurs during drying, while for coated textiles fixation of the coating might take place simultaneously with the drying.

**7. Simultaneous sterilisation**
For many products, especially in the food en feed industry, the demand for safe products increases. Sterilisation or decontamination of for example pathogens, salmonella, etc. can be realised during SHS drying.

## 5.3 Drawbacks in praxis

**1. Steam tight entrance and export constructions necessary**
At SHS drying the drying process has to be closed in order to prevent the hot and moist steam to enter into the surroundings. Also for recovery of the heat available in the excess steam a closed process is necessary. This sets demands on the

construction of the dryer and the connecting ductwork and on the entrance and export constructions. Sluices, rotating valves, worms, small envelopes, etc. are used to prevent steam to leak out of the dryer and to prevent air to enter the drying process.

**2. Higher product temperatures**

The products to be dried take on the wet bulb temperature during the so-called constant rate drying phase”, as long as their surface is still wet. This temperature is higher in a steam atmosphere then with hot air drying, although it is dependant on the steam pressure in the dryer. Higher product temperatures are sometimes unwanted, especially for food products that get (over)cooked. Some products might become sticky, melt or lump, caused by higher product temperatures.

**3. Condensation at incoming product**

Inevitable some condensation will occur on the cold incoming products in a SHS dryer. This causes the product to heat up very fast, because the heat of condensation comes available, but will also wet the product temporarily.

**4. Stainless steel equipment**

During start up and shut down some condensation of the steam might always occur. For corrosion prevention stainless steel equipment might be necessary.

**5. Fouled condensate**

With SHS drying the majority of the emissions will appear in the steam condensate that may result in contaminated condensate. Attention is necessary for the heat exchangers where the condensation takes place and the cleaning of the condensate.

## 5.4 Other comparable drying technologies

There are other drying technologies with partly have the same advantages as SHS drying, especially that the evaporated water comes available as steam.
This occurs at indirect heated dryers, where no air is added or let in to the drying process. The evaporated water will first displace the air that is present in the dryer at the start up, and will after some time come available as steam. These dryer types have the same advantages as SHS drying, like an inert steam atmosphere, the possibility of energy saving through heat recovery (depending on the pressure of the vented steam), no fire and explosion risk, etc. Sometimes additional heat treatment is possible in a SHS atmosphere, also in these drying technologies, like sterilising, enzyme inactivation or other thermal processes.

# 6. Overall conclusions

SHS drying is already quite widely applied in industry, with over 100 large-scale applications. There is a limited number of SHS dryers commercially available and the applications are limited to certain sectors and applications.
Like with all other dryers most SHS dryers and their manufacturers are focussed on specific products, industrial branches and throughputs. This give need for further development of existing equipment to new applications and new process and equipment development for new applications that cannot be covered with existing equipment.
Quite a few SHS dryers are under development at machine builders and at Universities and institutes.
It is realistic to expect SHS drying to find wider applications in the coming years, because the now available equipment has proven to be reliable under industrial circumstances. Knowledge on the SHS technology and on the effects of the steam atmosphere on the product qualities is also growing. This will stimulate the applications.
The possible applications are limited due to the fact that there is only equipment available for certain applications. Ongoing developments, supported by pilot facilities to judge on the product quality and processing aspects, will broaden applications.
Most realised SHS dryers are applied for drying of bulk streams in the feed, biomass and food industries.
Throughputs are already quite big and further up scaling does not seem a problem.

The following SHS dryers are really applied in industrial applications:
- GEA Exergy Barr-Rosin dryer
- BMA / NIRO fluid bed SHS dryer
- Eirich mixing SHS dryer
- Swiss Combi Ecodry
- Moenus (former Babcock)
- CDS airless dryer
- Hosokawa pneumatic SHS dryer
- HB Group, timber drying rooms

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# 8. Authentication

Name and address of the principal:
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August-Gottlieb-Strasse 5
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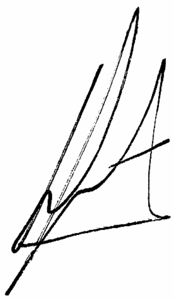
Names and functions of the cooperators:
H.C. van Deventer

Names and establishments to which part of the research was put out to contract:

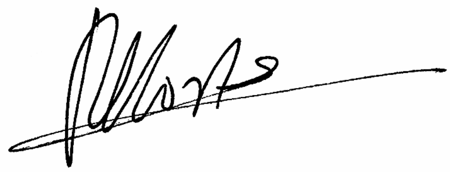
Date upon which, or period in which, the research took place:
August 2003 - June 2004

Signature:



H.C. van Deventer
project leader

Approved by:



P.S.R. Kosters
head of department

# Appendix A Principles of SHS drying

The basic principle of super heated steam, SHS, drying is that SHS is used as the drying medium in direct contact with the product to be dried.
The pure steam atmosphere can be achieved by starting with direct steam injection that washes out the air originally present in the dryer. The steam drying can start directly after this washing. Because steam is produced in the process, by the evaporation of water, no fresh steam is used during drying and the SHS drying process produces steam.
Another way to start up a SHS drying process is by recirculating the air inside a closed dryer over an indirect heat exchanger. The recirculating medium, air with water vapour mixture, is heated indirectly to above 100 °C. The evaporated water increasingly replaces the air and after a relatively short time the atmosphere completely consists of superheated steam. This principle is sometimes called “Airless drying”.

In both cases the majority of the steam is recirculated in a closed loop and indirectly superheated again before it enters the dryer.
Only an amount of steam representing the evaporated water is removed from the recirculating steam. This excess steam can be used for energy recovery, either directly by injection in water or steam networks, or indirectly by heating up water through condensation.
The principal scheme of SHS drying is given in Figure A.1.

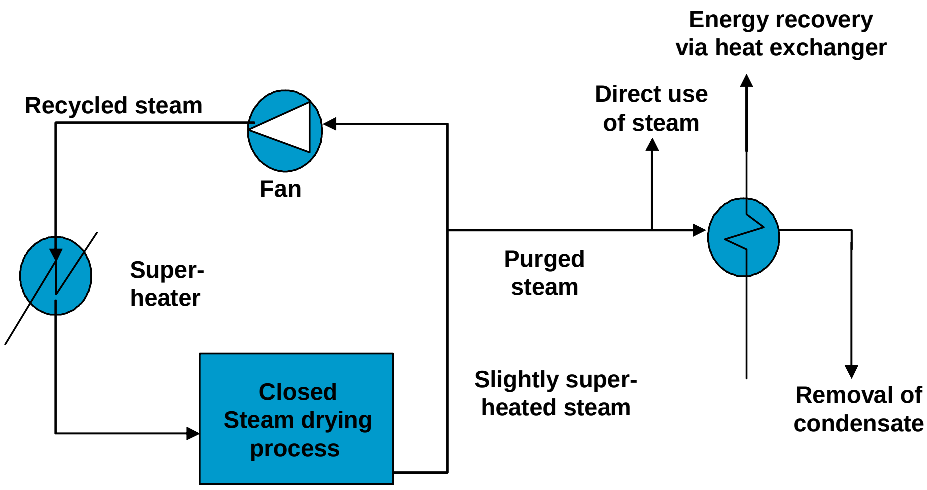



*Figure A.1 Scheme of superheated steam drying.*

In many aspects SHS drying is similar to drying with hot air, the most common drying principle. In both cases the drying medium, SHS or hot air, delivers the heat for heating up the wet product and the evaporation of water i.e. drying. The drying medium also takes away the evaporated water in both cases. The differences however are also clear and relevant. With hot air drying the evaporated water is included in the air thus moistening the drying air. This drying air is transported to the environment. Although it contains still all the heat of evaporation, this energy only comes available when the water vapour is condensed, which occurs at the dew point temperature of the air – water mixture, that is quite low, typically 40 – 70 °C. Figure A.2 shows the wet bulb temperature for a certain range as a function of the absolute humidity of air and the air temperature.

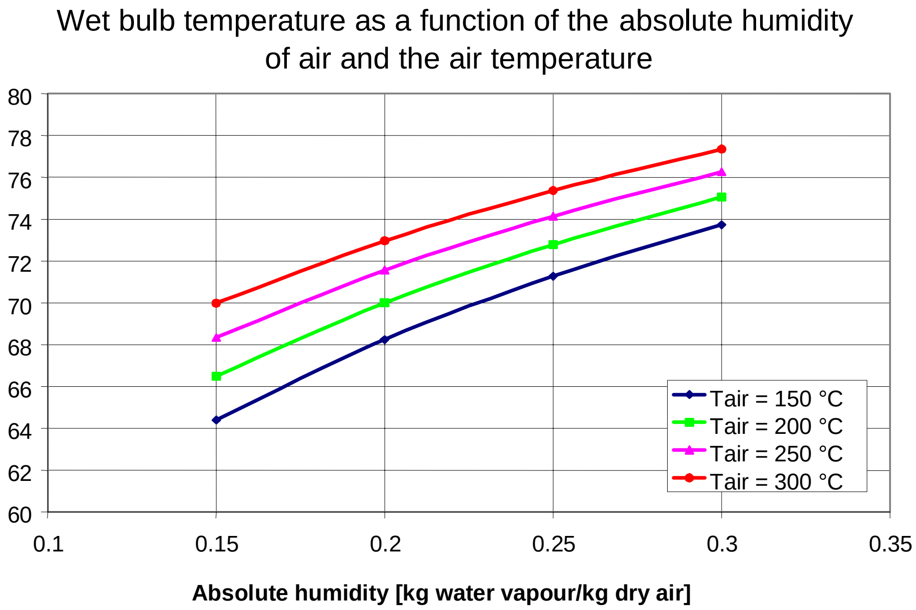



*Figure A.2 Condensation temperature in relation to the pressure.*

Another basic property of SHS drying, compared to hot air drying, has to do with the product temperatures during drying. In general we can distinguish between 3 drying periods:

1. The first drying stage is the heating up of the product, where only limited drying takes place.
2. The second stage is the so called ‘constant rate drying period’, where the product is still wet on its surface and the drying speed is constant, depending on the heat transfer from the drying medium to the product. In this stage the product temperature is constant at the wet bulb temperature.
3. The last stage is the ‘falling rate drying period’, where the surface of the product falls dry and the water has to be transported to the surface by inner diffusion. During this stage the drying speed decreases while the product temperature increases and will finally reach the temperature of the drying medium.

There is an essential difference in temperature behaviour between hot air drying and SHS drying. The wet bulb temperature during the ‘constant rate drying period’ is lower, 40 to 70 °C, with hot air drying compared to SHS drying where the wet

bulb temperature equals the condensation temperature of the steam. The final and maximum product temperature is equal to the SHS temperature.
Figure A.3 shows a typical progress of the product temperature during hot air and SHS drying.

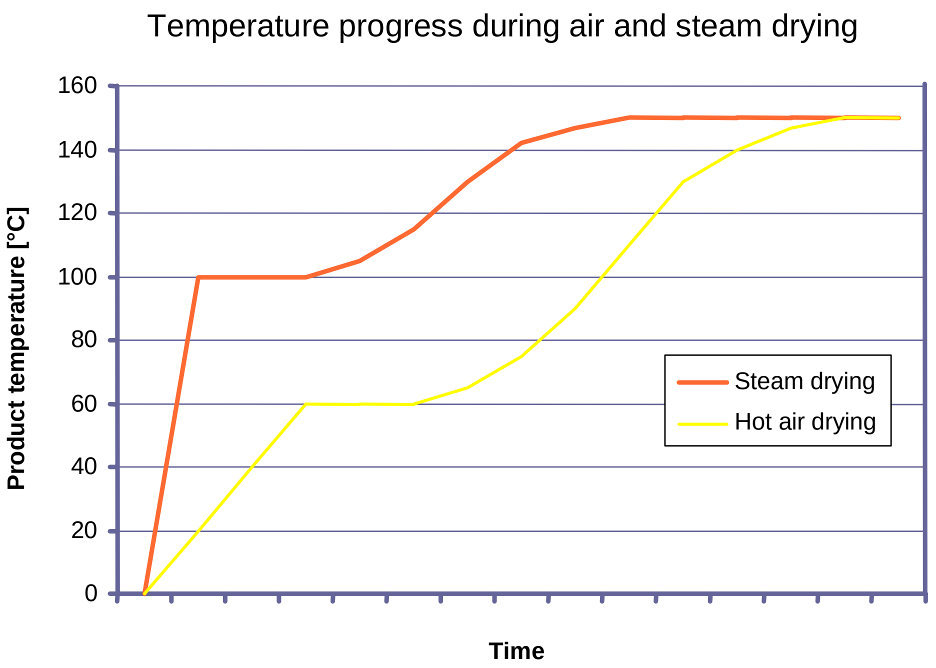



*Figure A.3 Temperature progress during hot air and SHS drying.*

The product temperature during SHS drying rises more quickly compared to hot air drying. This is caused by the condensation of steam on the product. As soon as the product temperature reaches the wet bulb temperature of the steam, 100 °C at 1 bar absolute, the product starts to dry. In this ‘constant rate drying period’ the product temperature is dependent on the steam pressure.
Figure A.4 shows this dependency of the product temperature from the steam pressure.

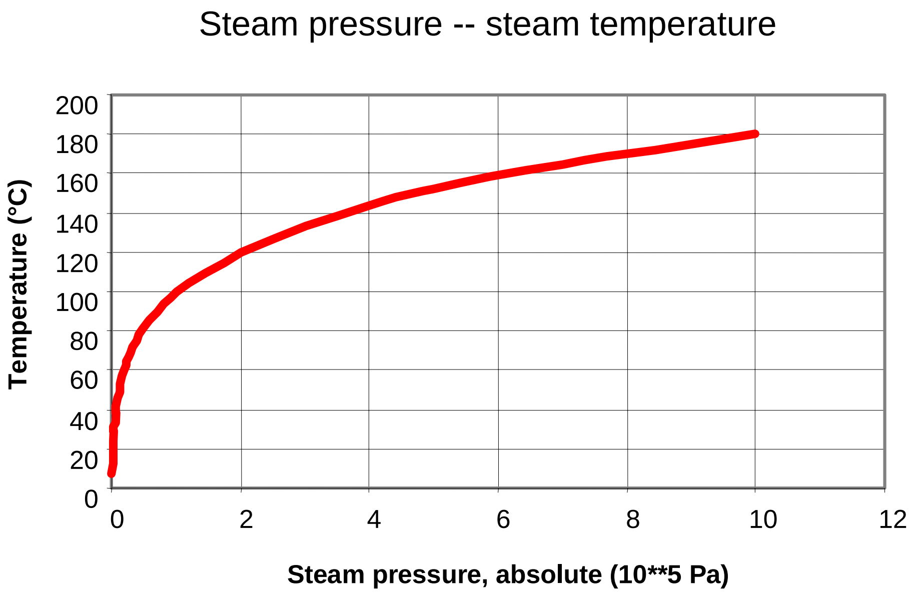



*Figure A.4 Product temperature during the 'constant rate drying period' versus the steam pressure.*

From this figure it is clear that the product temperature, during the constant rate drying period, will vary with the steam pressure.
At higher pressures the product temperatures is higher. The heat that can be recovered from the excess steam comes available at higher temperatures that, depending on the local situation, can be very beneficial. Sometimes however, the product to be dried cannot stand these higher temperatures. Then atmospheric or even vacuum pressures have to be applied to keep product temperatures sufficiently low.

**Remark:**
There are some other dryer types that produce steam, just like the SHS dryer. Examples are vacuum dryers, paddle dryers, etc. This happens at any drying principle where the heat is added to the drying process indirectly and where no air is let into the dryer. When the evaporated water escapes the dryer without mixing it up with air, the dryer produces pure steam. We however do not consider these dryer types as SHS dryers because the drying principle is completely different.

# Appendix B Comparison steam and hot air drying

For SHS drying often drying with hot air is the reference. Hot air drying is the most commonly applied drying principle that encloses many different kinds of dryer types. Because SHS is a gas as well, many SHS dryers are comparable with hot air dryers with respect to construction and way of operation.
The most important differences have to do with the differing physical properties of SHS compared to air, like specific enthalpy, specific heat, viscosity and heat conductivity.

The graph below gives the properties for pure air, left side, and pure steam, right side, at 300 °C as an example. Also the properties for mixtures of dry air and water vapour can be extracted.

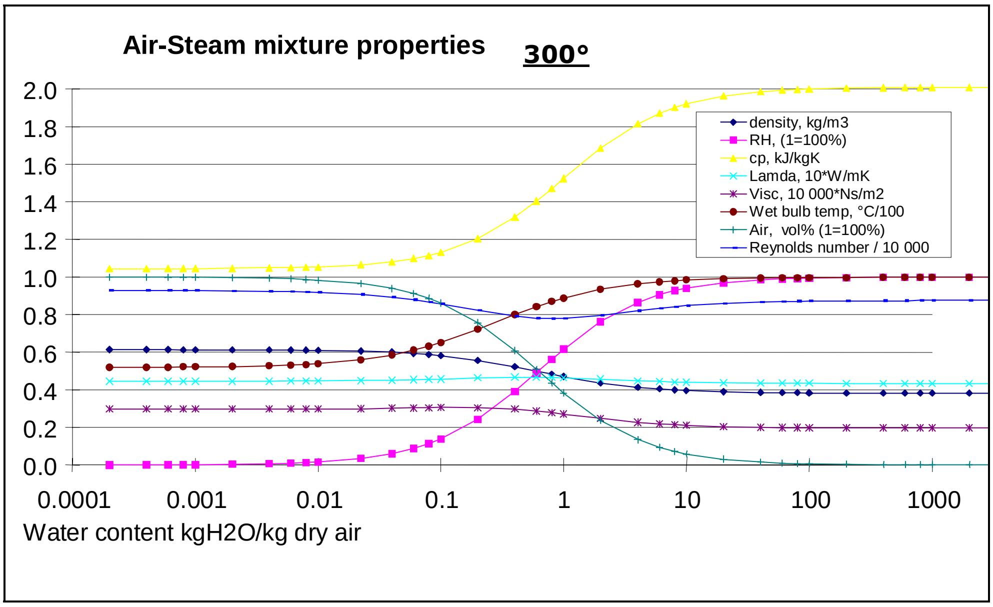



*Figure B.1 Physical properties of steam-air mixtures.*

The higher specific heat of the SHS causes a higher drying rate. On the other hand the temperature difference between the drying medium and the product at constant rate drying period is lower at SHS drying, because the wet bulb temperature is higher.
This leads to a so called inversion point, that is the temperature at which the evaporation rates have the same value for both mediums. Above the inversion temperature the rate of drying is higher with superheated steam than with hot air. Inversion temperatures are typically in the range of 150 - 200 °C, when the mass flow rates of steam and air are equal.

# Appendix C Complete contact list for interviews

Following the lists of the persons and organisation that have been contacted in the framework of this study. Mostly the interviewing was on the basis of the questionnaire by telephonic or E-mail questioning.

Persons and organisation contacted:

Builders of SHS equipment:
1. GEA Exergy AB, Gothenburg, Sweden; Daniel Frosterud, Ian Petterson; Exergy Steam Drying / Processor.
2. BMA Braunschweigische Maschinenbauanstalt Dr. Andreas Lehnberger / Dr. Lothar Krell, Sugar beat pulp dryers.
3. Carlille Stork Netherlands, Anton Bouman; former supplier of Exergy Dryers.
4. SWISS COMBI, Mr W. Kunz; EcoDry.
5. Fa. Eirich, Stefan Gerl, Eirich steam dryers.
6. Moenus (ex Babco-Therm,), Mr. F. Kunzmann; dyeing, fixation and drying in SHS.
7. CDS Group, Th. Stubbing, Graham Bird; airless dryers.
8. Hosokawa Nl, The Netherlands, David Hollestelle; flash steam dryer.
9. Pinches Consolidated Industries, Max Morley, New Zealand; full scale pilot of a rotary drum type of SHS dryer (information promised, not received).

Industries:
1. Henkel, Austria, Dr. Wilfried Rähse; SHS dryer for detergents.
2. Vlisco, The Netherlands, Jan van Driel, Paul Oude Lenferink; SHS drying and tri removal.
3. AKZO, Kees van ’t Land, former drying expert from AKZO Nobel.
4. Bayer, Dr. D. Gehrmann, former drying expert from Bayer Germany.
5. Avebe, The Netherlands, J. Zuur; SHS drying of fibres and proteins.
6. Bunge (former Cereol) Germany, Mr. R. van der Poel; drying and thermal treatment of feed components.
7. Techwood, The Netherlands, Mr. W. Derksen; SHS drying of wood fibres.

Institutes:
1. ENSIA, France, J. Vasseur; SHS drying general.
2. TNO, The Netherlands, Wood drying, Mr. M. Riepen.
3. SINTEF, Norway, Prof. O. Alves-Filho, SHS drying general.
4. DK Teknik Energy & Environment, Mr. J.S. Nielsen, SHS drying general.
5. WKI Fraunhofer Institue for Wood Research, Dr. Andreas Hinsch, Dr. Timo Gruber, steam drying wood chips.
6. Techniprocess, France, Mr. Marc Sionneau, SHS drying general.
7. SINTEF, Norway, Dr. Odilio Alves-Filho, SHS drying general.

8. VTT, Finland, Harri Kiiskinen, SHS drying of paper.
9. Prof. David Reay, SHS drying general.

Universities:
1. University of Singapore, Prof. Arun Mujumdar and Prof. Sakamon Devahastin.
2. University of Magdeburg, Germany, Dr. S. Heinrich, SHS drying general.
3. University of Karlsruhe, Prof. M. Kind, SHS drying general.
4. McGill University Montreal, Canada, Dr. Tadeusz Kudra, SHS drying general.
5. University of Lyon, France, Prof. J. Andrieu, SHS drying general.
6. Umist, UK, Dr. Jiri Klemes
7. Ecole des Mines, Alby, France, Prof. Didier Lecomte.

# Appendix D Suppliers of SHS dryers, additional information

## D.1 GEA Exergy Barr-Rosin dryer
http://www.barr-rosin.ca/english/products/b13.html

The Exergy Steam Dryer is a superheated steam drying system for solid materials like pulp & paper, wood chips, saw dust, bark, sugar beat pulp, peat, sludge and wet solid waste. The dryer consists of closed loop of ductwork, where superheated steam is circulated by a fan. (See figure D.1).

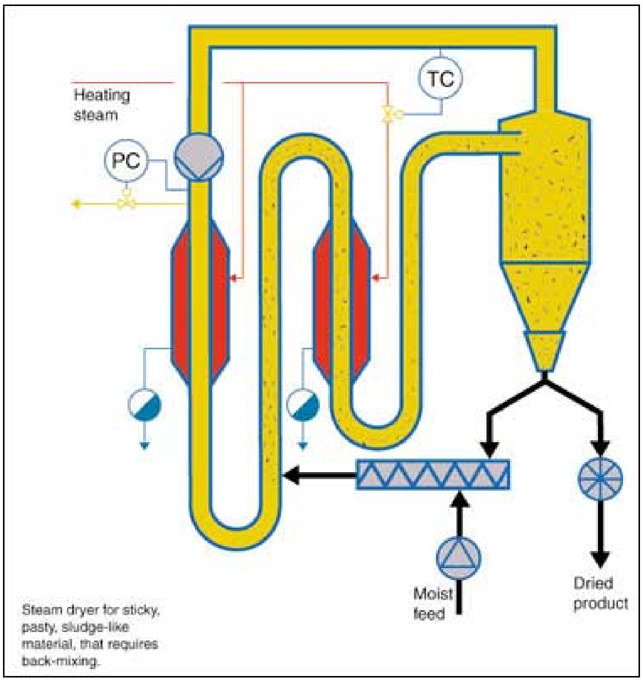



*Figure D.1 Principal scheme of a GEA Exergy Barr-Rosin dryer.*

The steam originates from the wet material and is super heated in a tubular heat exchanger by a primary heat source. High-pressure steam, electricity, or flue gas can be used for the indirect heating. About 80-90% of the heating energy can be recovered as low-pressure steam, i.e. the excess steam that corresponds to the evaporated water. Usually it is integrated with other processes, in Sweden often also for district heating. This also implies that all emissions to the environment are avoided. Emissions from the product appear in the condensate that might have to be treated separately.
The wet material is introduced to the circuit, dried quickly during its pneumatic transport through the ducts and then separated in a cyclone. The residence time is usually only in the range of 10-30 seconds, but still a very high dryness can be achieved.

The short residence time and lack of air usually gives a less burnt or oxidised product, valuable especially for the cattle feed industry. Since the process is closed, all

emissions to air are avoided and it is possible to treat the condensate separately. The Exergy dryer can operate at a few bar gage, thus the steam vaporised from the wet material can be used as a secondary steam. By utilising this steam, approximately 80-90% of the energy input can be recovered.
For sticky sludge like materials, such as sludge from waste water treatment or spent grains from alcohol production (DDGS), back mixing of dry product with the wet is required to avoid clogging in the inlet.

**List of exergy steam dryers in operation**
**(or in course of construction)**

1. CTMP — Rockhammars Bruk, Frövi, Sweden
   Market pulp, CTMP, Production 8 tons/h, capacity 8 ton/h water evaporation. Start-up 1979. Modifying and increasing capacity to 8 tons/h, start-up 1987.

2. Hog Fuel — MODO-Cell, Husums Sulfatfabrik, Örnsköldsvik, Sweden
   Spruce and birch bark, production 15 tons/h, capacity 21 tons/h water evaporation. Start-up 1982, closed down 1995.

3. Sugar Beet Pulp — Sockerbolaget, Köpingebro Sockerbruk, Ystad, Sweden
   Dietary fibre from sugar beet, production 400 kg/h, capacity 1,7 ton/h water evaporation. Start-up 1983.

4. Mineral Fibre — Laxå Bruk, Laxå, Sweden
   Mineral wool fibre to replace asbestos, production 500 kg/h, capacity 200 kg/h water evaporation. Start-up 1984.

5. Corn Gluten Fibre — Martorell, Spain
   Cattle feed from corn fibres and steep water. Start-up 1986, closed down 1994.

6. Sugar Beet Pulp — Fibrex, Köpingebro Sockerbruk, Ystad, Sweden
   Dietary fibre from sugar beet, production 2 tons/h, capacity 8 ton/h water evaporation. Start-up 1986.

7. Corn Gluten Fibre — ADM Corn Sweeteners, Decator, Illinois, USA
   Cattle feed from corn fibres and steep water. Start-up 1987.

8. Biomass — Kemira Oy, Oulu, Finland
   Milled Peat for gasification, production 40 tons/h, capacity 40 ton/24 h water evaporation. Start-up 1988. Delivered from joint venture with Mo-Do Chemetics and Ahlström

9. Biomass Härjedalens Mineral AB, Sveg, Sweden
(2 parallel lines) Peat for fuel briquettes, production 2 x 54 tons/h peat, 2 x 58 ton/h water evaporation. Start-up 1988. Designed by GEA and delivered by MoDo Chemetics.

10. Rape Seed Exab, Karlshamn, Sweden
Drying of animal feed for improved protein value, production 21 tons/h, capacity 500 kg/h water evaporation. Start-up September 1988.

11. Sugar Beet Pulp Minn-Dak Farmers Co, Whapeton, North Dakota, USA
Dietary fibre from sugar beet, production 2 tons/h. Start-up November 1988, closed down 1995.

12. Flour Francereco, Beauvais, France
Drying of wheat flour, research plant, production 30 kg/h, capacity 10 kg/h water evaporation. Start-up February 1989.

13. Corn Gluten Fibre Glindia, India
Cattle feed from corn fibres and steepwater. Start-up July 1990, no longer in operation.

14. Corn Gluten Glinda, India
Drying of gluten from corn. Start up 1991, no longer in operation.

15. Municipal Sludge GRYAAB, Gothenburg, Sweden
Demonstrating plant Ryaverken, production 350 kg/h, capacity 250 kg/h water evaporation. Start-up June 1992.

16. Transportable dryer skid moved for joint development work at Terra, Arnhem, Holland 93/94, Donaueschingen Germany and Dairy Gold Ireland. Products based on various sludges.

17. MVR – Pilot plant EDF-Renardieres, Moret-Sur-Loing, France
MVR drying of sludge and biomass, pilot plant now used for tests at GEA. Production 10 tons/24 h, capacity 3 ton/24 h water evaporation. Test ongoing 1993-1995.

18. Corn Gluten Fibre OJI Corn Starch, Chiba, Japan
Start-up autumn 1994.

19. Sawdust & Wood Chips Skellefteå Kraft AB, Hedensbyn, Sweden
Production of wood pellets for fuel, 50 ton/h, capacity 25 ton/h of water evaporation. Start-up summer 1997.

20. Sawdust/Wood fiber Techwood, the Netherlands
    Drying of sawdust and wood fibre for production of composite material profiles and boards. Start-up summer 2000.

21. Sawdust/Wood fiber A-cell Cellulosic Technologies
    Pilot plant for drying of sawdust and wood fibre for production of composite material profiles and boards. Development project sponsored by the National Board for Technical Research and Development (NUTEK). Start-up summer 2000.

22. Oil seeds Cereol Deutschland GmbH
    100 tons/h rapeseed, soya beans and sunflower seed processing plant for production of by-pass meal. Start-up June 2002.

23. Distillers Grain Sedamyl, Italy
    Drying of distillers' grain from ethanol production. Capacity 1,7 t/h water evaporation. Start-up November 2002.

24. Woodchips & sawdust Energi E2 A/S, Denmark
    Milling, screening, handling and drying of woodchips from Junckers Industrier A/S flooring production. Dried product to be pelletised. Capacity 50 t woodhips/h, 22 tons/h of water evaporation. Delivery including re-boiler for fresh steam generation. Start-up spring 2003.

**Recent important test runs and full scale test for new applications.**

| | |
|---|---|
| Animal Feed | Enzyme inactivation and gelatinisation of starch in various animal feeds. |
| Animal Feed | Killing of salmonella in rape seed meal. Conducted together with Swedish Veterinary Institute that allows Karlshamn to export and sell their ExPro meal with a guarantee it is free from salmonella. |
| Flaked Rape seed | Heat treatment of flaked seeds in order to improve quality of pressed and extracted rape oil. Full scale factory production at Karlshamn. Similar tests conducted on Soya and sunflower seeds in pilot scale. |
| Tobacco trials | Drying, expansion and flavour modification of tobacco in pilot plant for many customers. |
| Fibre sludge | Drying of fibre sludge from waste water treatment at a pulp mill. |

## D.2 BMA / NIRO fluid bed SHS dryer

http://www.bma-de.com

The BMA / NIRO fluid bed SHS dryer is developed in Denmark for the sugar industry by De Danske Sukkerfabrikken, DDS, and first placed at the Stege Sugar Factory in Denmark. Later on the equipment was commercialised for beet pulp drying by NIRO. The concept is now brought to the market by BMA AG. Since September 1990 14 dryers, with capacities varying from 25 to 50 tons of water evaporation per hour, are installed, only for sugar beet pulp drying.
The working principle is a pressurised fluidised bed dryer, with indirect heating with high-pressure steam. The dryer consists of a large vertical cylinder with vertical segments. The product is fluidised and taken up in a segment by the SHS and falls down in the next segment. In this way all 14 segments are passed through until the product is dry and leaves the dryer. The pressurised SHS is circulated by a fan and heated by an internal heat exchanger, heated with high-pressure steam. Input and output are realised by means of screws. The pressure inside the dryer is approximately 3 bars. The residence time of the sugar beet pulp is approximately 8 minutes.

These kind of systems can also be delivered or modified by EnerDry ApS, the company of Mr. Arne Sloth Jensen
http://www.enerdry.dk/index.php?id=397

BMA

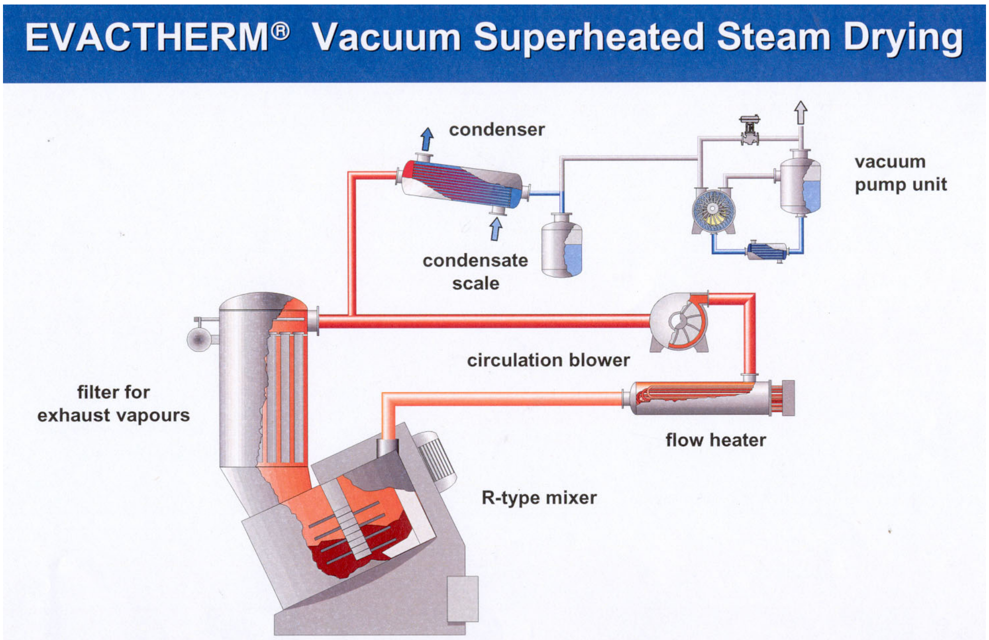
**Reference List** January 2004
(Pulp only)

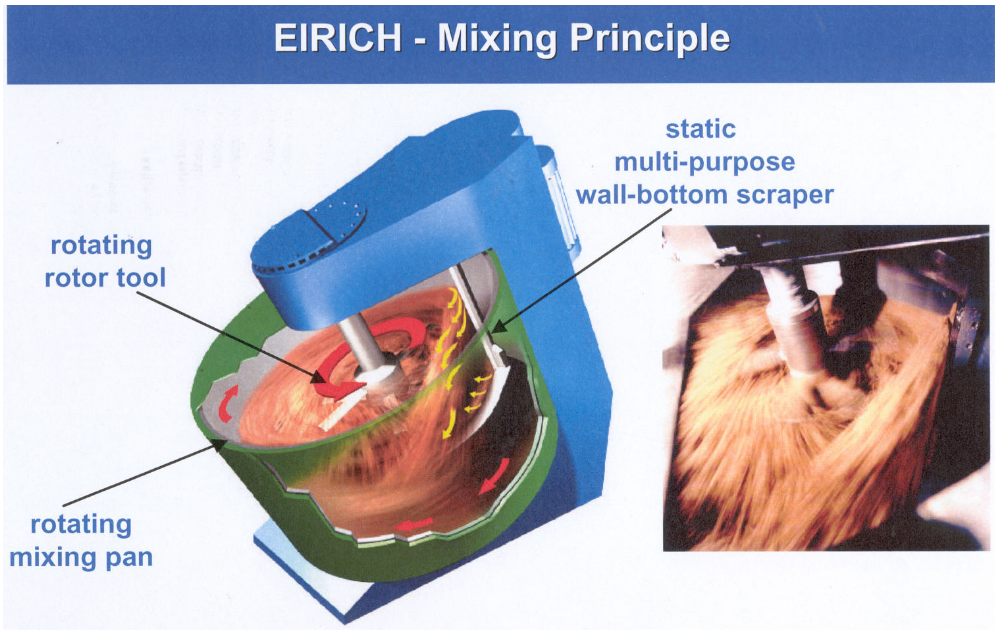
| No. | Location | Customer | Country | Start up | Size | Evaporation Rate |
|---|---|---|---|---|---|---|
| 1 | Nangis | Lesaffres Féres S.A. | France | Sep 1990 | 8 | 25 t/h |
| 2 | Cagny | Géneral Sucrerie SNC | France | Sep 1992 | 8 | 25 t/h |
| 3 | Miranda | Ebro Agricolas Compania | Spain | Nov 1992 | 8 | 25 t/h |
| 4 | Könnern I | Pfeiffer & Langen | Germany | Oct 1993 | 10 | 40 t/h |
| 5 | Könnern II | Pfeiffer & Langen | Germany | Oct 1993 | 10 | 40 t/h |
| 6 | Anklam | Danisco A/S | Germany | Oct 1993 | 8 | 25 t/h |
| 7 | Güstrow | Zucker AG Uelzen/Braunschweig | Germany | Oct 1993 | 10 | 40 t/h |
| 8 | Klein Wanzleben I | Zuckerverbund Nord AG | Germany | Oct 1994 | 10 | 40 t/h |
| 9 | Klein Wanzleben II | Zuckerverbund Nord AG | Germany | Oct 1994 | 10 | 40 t/h |
| 10 | Puttershoek | Suiker Unie | Netherland | Sep 1994 | 10 | 40 t/h |
| 11 | Renville I | SMBSC | USA | Sep 1999 | 10 | 40 t/h |
| 12 | Renville II | SMBSC | USA | Sep 1999 | 10 | 40 t/h |
| 13 | Uelzen | Nordzucker AG | Germany | Oct 2002 | 12 | 50 t/h |
| 14 | Clauen | Nordzucker AG | Germany | Sep 2003 | 12 | 50 t/h |

## D.3 Eirich mixing SHS dryer

**http://www.eirich.com/index.html**

The German firm Maschinenfabrik Gustav Eirich GmnH & Co KG, delivers a batch wise operating SHS dryer, Evactherm. In a rotating pan the product is intensively mixed and other treatments like mixing, granulation etc can be realised simultaneously. The drying process and the recirculating steam are operated with under atmospheric pressure.
Applications are sludges, with recoverable heavy metals, desulphurisation sludges, ferrites, brake lining, coating sludges, catalysts, pigments, wash powder additives, etc. Some 12 SHS dryers are in operation now.



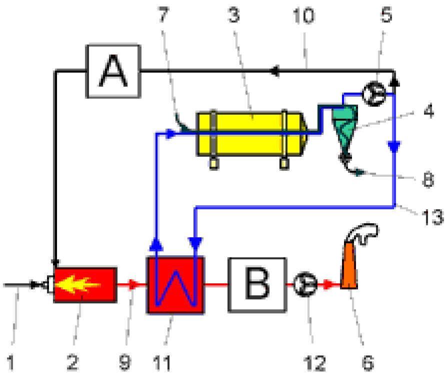

EIRICH - Mixing Principle
static
multi-purpose
wall-bottom scraper
rotating
rotor tool
rotating
mixing pan

# D.4 Swiss Combi Ecodry


***ecoDry*** is a patented drying process which thanks to a closed-loop vapour system, destroys all odours and emissions by internal incineration. In contrast to conventional drying concepts, no exhaust gas treatment is required such as regenerative combustion, electroscrubbing, etc.

Outstanding benefits of the ***ecoDry*** process:
- Negligible emissions
- Almost complete freedom from odours
- Gentle drying for optimal product quality
- Minimal energy consumption
- High energy recovery potential (dewpoint temperature 90 to 95°C).

***ecoDry*** lines can be extended with a belt drier into the ***ecoTwin*** concept, a 2-stage drying process which enables additional energy savings.




*1. Burner (gas, oil, dust)*
*2. Kiln*
*3. Drying drum*
*4. Cyclone*
*5. Circulation blower*
*6. Exhaust stack*
*7. Wet product*
*8. Dry product*
*9. Hot gases*
*10. Vapour recycling*
*11. Heat exchanger*
*12. Flue gas extractor fan*
*13. Vapour loop*

Heat recovery options:

A: Direct vapour recycling: low-temperature dryer, steam generator, hot water supplies, etc.

B: Direct exhaust gas utilization: low-temperature dryer, through-flow dryer, hot water supplies, etc.

Only 10 months after signing of contract, which for the first time applies our *ecoDry* system for the ethanol industry, our client in the Midwest of the US could start up his new drying plant in May 2002.

Preliminary emissions testing indicate that the system will meet not only the guaranteed levels, but also the new, much tighter limits set by the EPA for the ethanol industry.

The patented *ecoDry* system is a closed loop rotary drying system, drying the product in superheated steam. The system utilizes aN internal thermal oxidation which takes care of all emissions while operating with very low primary energy consumption (natural gas, oil, coal or other fuels). In addition to excellent product quality, the system offers a great potential for energy recovery out of the closed loop to drive e.g. an evaporator at the same time.

## D.5 Moenus (former Babcock)

Moenus Artos Textilmaschinen GmbH from Germany delivers textile dryers for textile sheet with SHS impingement jets onto the surface. The sealing of the SHS drying section is realised by stratification, the textile web entering and leaving the closed steam cavity from under. Until now 2 SHS dryers have been delivered and first experiences are building up. One of the main advantages is the fact that drying is combined with fixation of reactive dyeing on the textile in an atmospheric steam atmosphere.

## D.6 CDS airless dryer

### Airless drying technology for energy savings and other process and environmental benefits

*by Thomas J. Stubbing, Heat-Win Ltd.*

**Energy Savings**

Our internationally patented industrial airless drying technology is so called because often more energy can be saved by not heating air than by the subsequent recovery of energy from the steam and flue gases which are separately vented from what is, in fact, a superheated steam dryer operating at atmospheric pressure and therefore relatively inexpensive to build.

Experience shows that at least 20% and typically around 50% of industrial drying energy can be saved when an air through-flow is avoided and that, of the remaining energy consumption, up to around 90% can be re-used, either by integration with other processes requiring heat or to provide space heating, or within the airless dryer itself.

**Other advantages**

Other already recognized advantages of airless drying include the following:

- Drying time reductions of up to around 80% with consequent dryer investment, floor space and working capital savings, or increased output from the same floor space.
- The ability to dry virtually all products and materials which are able to tolerate 100 degrees C + without damage.
- The elimination of the drawing into the building of a substantial volume of air, thus significantly reducing space heating costs.
- Virtual elimination of noxious emissions and reduced environmental protection costs.
- Product sterilization due to its temperature reaching 100 degrees C+.
- Separation and recovery of valuable essential oils and other volatile organic compounds (VOC's) contained in some moist materials.
- Recovery of the removed moisture as a supply of de-mineralized water.
- Conditioning of the dried material and/or prevention of oxidation, which can improve output quality or performance and/or reduce subsequent processing costs.

**A brief process description**

To replace the air initially contained in an airless dryer with a superheated steam atmosphere, the air is recirculated over an indirect heater, through or around a moist product and back to the heater. This heats the air and the dryer's internal components to above 100 degrees C, while the moist product’s surface temperature rises towards 100 degrees C.

*During this warm-up phase*
- The saturation temperature of the air in the dryer rises towards 100 degrees C and attains it when the moist product's temperature has also risen to 100 degrees C, while
- Steam generated by evaporation of some of the product's surface moisture increasingly displaces the initially contained air through a vent and replaces it with virtually pure superheated steam at a temperature above 100 degrees C.

*During the subsequent airless drying phase*
- The superheated steam atmosphere is recirculated over the indirect heater and through or around the product until it is dry or the required degree of dryness has been reached, and
- The steam generated from the removed moisture is vented from the dryer.

**Energy re-use and other benefits**
*By condensing the vented steam*
- Its latent and sensible energy is recovered for re-use, either by heating, for example, process water or air or, if it is first compressed to raise its saturation temperature to above 100 degrees C, by recycling its latent energy back into the drying process by condensing it in a heater battery upstream of the dryer's indirect heater.
- The removed moisture is recovered as a supply of de-mineralized water after any sometimes valuable volatile organic compounds (VOC’s), which may also have been evaporated from the product, have been separated from the condensate for sale or appropriate safe disposal.

*By employing the indirect heater’s flue gas energy*
The around 15 to 20% of an airless dryer’s thermal input contained in its indirect heater’s typically 250 to 300 degrees C flue gases can be used advantageously either:
- Indirectly, for example to heat another process fluid such as water or air.
- Directly, for example by adding it to a flow of air already heated to around 95 degrees C by condensing the vented steam as described above and then using the around 130 degrees C mixture to operate a conventional hot air dryer.
- That conventional dryer may be used as a pre-dryer to heat to around 60 degrees C and partly dry the airless dryer's moist product input.
- The combined effect of the above can reduce the heat input required to less than 2 MJ/kg of moisture removed.

**Batch and continuous airless dryers**
The above applies to both batch and continuous airless dryers, the only difference being that with batch dryers the process is repeated after each unloading and re-

loading of the machine, whereas with a continuous dryer the drying phase can continue indefinitely.

*Batch dryers*
In accordance with our US Patent 5,228,211 and corresponding international patents:

- Each batch dryer has a drying enclosure containing either a fixed product presentation for drying mechanism, for example shelves or trays, or a moving mechanism such as the rotating drum in a tumble dryer, which optimizes heat transfer from the initially contained air recirculation during the warm-up phase and from the superheated steam recirculation during the drying phase.
- The initially contained air and then the superheated steam atmosphere is recirculated by a fan, firstly through an indirect heater to raise the recirculation's temperature and then through or around the moist product to which some of its thermal energy is transferred. This transfer lowers the recirculation's temperature before it again passes through the indirect heater.
- The additional steam generated while drying proceeds is vented and condensed and its energy recovered for re-use, while the resulting condensate is available as a supply of demineralized water.
- On completion of each batch drying process, one or more gasketed loading doors are opened, the dried product removed and replaced by moist product. The doors are then closed, enabling a new process to begin.

Batch-wise mechanically sealed through-conveying of products was also provided for in the original patent application, but this arrangement has been abandoned in favor of the subsequent innovation described below.

*Continuous dryers*
In accordance with our US Patent 5,711,086 and corresponding international patents and patent applications, with continuous airless dryers:

- Moist products are conveyed upwards through an open duct into the drying enclosure,
- An appropriate presentation for drying mechanism conveys the product through the enclosure while it is being dried, and
- The dried product is conveyed or allowed to fall downwards out of the dryer, either through the same or a second open duct.
- The need for complex and costly mechanical sealing of the open ducts is avoided because, by venting the steam generated by the process at an appropriate level below the base of the drying enclosure but above the open lower ends of the duct or ducts, a steam/ambient air stratification layer forms at that level across the duct or ducts. This steam/ambient air stratification layer intimately embraces the rising and descending product and its conveyor or conveyors, thus providing an effective non-mechanical seal which inhibits inwards air movement and/or loss of steam.

**Ongoing development**

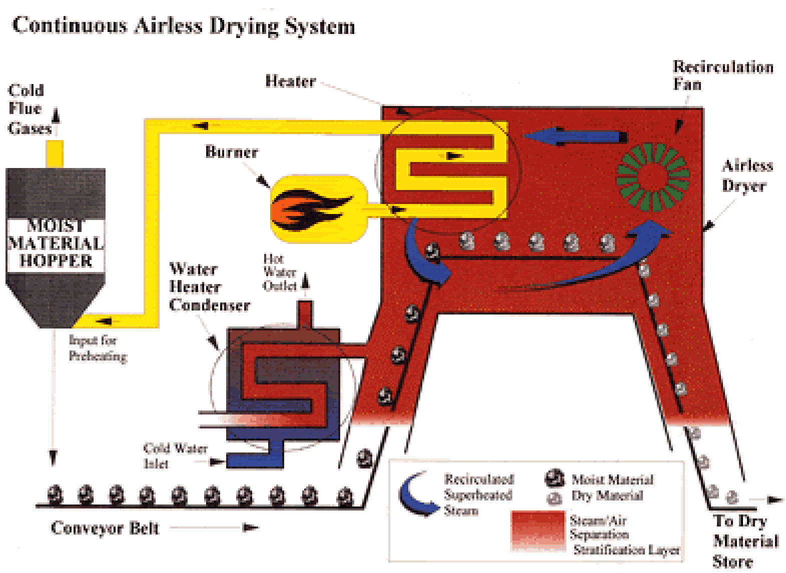
*Batch drying*

The first licensee, Ceramic Drying Systems Ltd., is now successfully selling airless dryers to the ceramic industry world wide and providing paybacks as short as six months on their customers' investment.

The batch drying process has also been demonstrated with the tumble drying of laundry, and with other materials such as paper industry sludges where the absence of oxidization is advantageous.

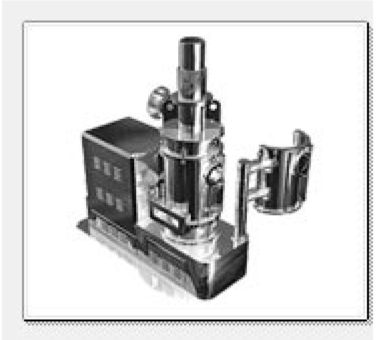
*Continuous drying*

Greenbank Technology Ltd. based in Blackburn, Lancashire, in close collaboration Mr. Thomas Stubbing of Heat-Win, have developed and mechanically applied a process for continuous drying of particulate and granular materials.




- The material is dried in a totally inert atmosphere of superheated atmospheric steam.
- The water content of the material is caused to 'flash off' to further steam, which may be later condensed (imparting energy returns) whilst supporting any suspended contamination.
- The system is safe, energy efficient and is environmentally friendly whilst eliminating the emission (and need for incineration off) volatile organic components.
- Trials to date include materials as diverse as paper mill waste sludge, food products and aluminum swarf contaminated with cutting oils.

## D.7 Hosokawa pneumatic SHS dryer
http://www.hmbv.nl/default.asp



**Working principle**
A specially designed feeder transfers the wet material into the grinding section of the dryer. The impact action of the grinding rotor disperses with tip speed from 50 up to 110 m/s the wet material into fine particles.

A hot air stream (or nitrogen or steam) from the heater is giving the energy for instant evaporation.

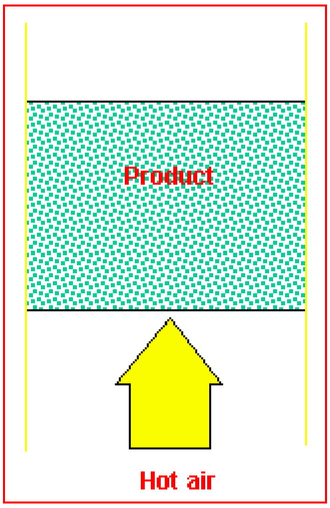
The Micron dryer or called also Drymeister is **a unique flash dryer using hot air or gas as drying media and combines three unit operations**.

**Drying, Grinding and Classifying in one machine**
The dried particles then enter the classifying zone in the top of the dryer. Fine particles below a specific set point leave the dryer at the outlet and are collected in a suitable filter. Coarse particles rejected by the classifier are internally recycled and returned to the grinding section for further processing.

The Hosokawa Flash dryer is **suitable for getting dry fine powders** with uniform particle size distributions in one step with the following products:
- Wet powders with agglomerates
- Filter cakes
- Press cakes after press filtration
- Slurries
- Thixotropic material
- Wet grinded nano particle products

Based on the amount of dispersion required during the drying process, the execution of the grinding section can be adapted.
Several rotors & classifiers give different degree of dispersion/grinding which can be summarizing as follow:
- Gentle dispersion
- High dispersion for solids
- Milling
- High dispersion for suspension and sticky/viscous liquids

**Schematic sketch of the heating principle of the Micron Dryer**
The Micron Dryer is a universal dryer combining direct drying. Heat is basically transferred into the product by a flow of gas to evaporate the solvents and volatiles.




Based on the application, different heating media can be used:
- **Hot-Air** (either directly heated by gas burning or through an heat exchanger)
- **Nitrogen** closed loop for explosive materials
- **Superheated steam** for higher capacities and sterilization of products

**Main features of the Hosokawa Flash dryer**
- **One single machine for 3 unit operations:** Drying grinding/dispersing and classifying in one, to save space and operational costs.
- **Particle size control**: The dynamic classifier ensures a uniform product both in moisture content and in particle size distribution of the product.
- **Minimal dust emissions:** The system operates under negative pressure which minimising dust getting into the environment.
- **Energy efficient operational plant:** Data have proven that this concept requires less energy in comparison to any other system with consumption of lower than 1 kW for evaporation of 1 kg water/h.
- **Multi purpose:** cakes or slurry in the same machine.

- **Excellent cleanability:**
- **Reliability & quality of manufacturing**
- **Number of references**

## D.8 HB Group, timber drying rooms

http://www.hb-almelo.nl/engels/Droogkamers/Hoogtemperatuuruk.htm

**Superheated steam drying**

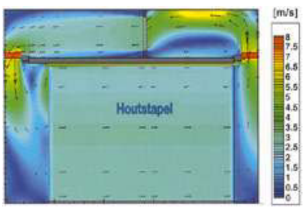
*How does it work?*




During the pre-heating phase all air initially present within the kiln will be replaced by steam. The relative humidity of the air during the pre-heating phase is kept at a maximum level close to 100% saturation. Venting will occur based upon the overpressure within the kiln. This results from the increase of temperature and the supply of steam.

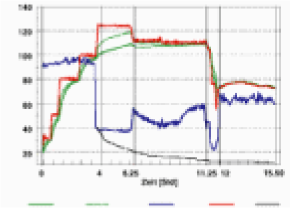
If the temperature of the drying medium approaches 100°C, the climate will have changed into saturated steam. If the saturated steam is heated within the kiln, the steam will become super heated and the free water inside the Timber will start to boil.

The temperature of the Timber will stay at the boiling point of water (100°C), as long as the moisture content is above the Timbers fibre saturation point. This boiling effect will cause a slight overpressure within the wood. This internal overpressure speeds up the moisture transport from the core to the surface of the Timber and consequently increases the drying rate.

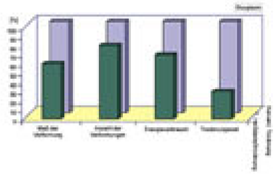



**Is the drying rate under control?**
The drying rate is determined by the energy supplied to the Timber. The energy supplied depends upon the air velocity within the kiln as well as the wet bulb depression. For example: With a super heated steam temperature of 110°C, and a wet bulb temperature (temperature of the Timber) of 100°C, the delta T will be 10°C. The drying rate would then be twice as high as with a steam temperature of

105°C. If the control system allows accurate temperature control within the kiln, then adjusting the temperature of the steam will afford the optimal drying rate.



**What will be the reduction in drying time?**
In general the drying time will be reduced with approx 50% in comparison to the regular drying process. The drying quality will be maintained at the same level.



**What happens to the wood quality?**
Since the temperature of the Timber being dried is above or equal to 100°C, the wood becomes supple. This elasticity will help to reduce the initial stresses present within the Timber. In combination with a top load on the Timber stack the reduction of a deformed and twisted product is substantial. At these drying temperatures less weight is required on top of the load to realise a substantial reduction in the Timber deforming in comparison to conventional drying. This is investigated in detail in the EU-funded project, titled “STRAIGHT”.

**What happens to the strength of the wood?**
As long as the temperatures used during the drying process are below 120°C, the strength of the wood will remain unchanged.

**What happens to the colour of the wood?**
The effect of steam drying on the colour depends of the type of wood species. The colour of planed Spruce is a slightly more yellow, as shown in the photo alongside.

**Can we save energy?**

In a steam drying kiln fresh air ventilation is not necessary to maintain the required wet bulb depression. This results in a considerable reduction of the energy consumption. Furthermore the reduction of drying time will substantially reduce the amount of electricity required for the fans.

# Appendix E Results of interviews

GEA Exergy Barr-Rosin Dryer / steam processor.
Based on interviews and documentation.

**Questionnaire**

*1. Products dried with superheated steam*
***Drying:***
Paper pulp, Grain, Cellulose derivates, Corn by-products, Mineral wool, Distillers grain, Wood chips, Spent brewers grains, Peat, Sugar beet pulp, Saw dust, Potato waste, Bark, Fish meal, Biomass, Tobacco, Sewage sludge, Fibre sludge, Manure, Citrus peel/pulp, Grass, Grape skins, Lucerne, Coffee grounds, Straw, Spices, Bagasse, Olive residues.
***Heat treatment***
Rape seed, Rape seed meal, Soya beans, Soy bean meal, Sun f lower seed, Sun flower meal, Linseed, Linseed meal.

*2. Industrial sector applying superheated steam drying*
See products.

*3. Throughput / evaporation capacity*
Pilot plant scale, full scale, 0.5 – 30 ton water evaporation /h.

*4. Drying system used, principle of dryer*
Pneumatic transport by SHS in a long, folded tube. Product feed by plug screws, dry product separated from the steam in a cyclone and removed through a rotary valve. Pressure inside the dryer: 1 – 5 bar.

*5. Drying system used, supplier of dryer*
This dryer is now delivered by GEA Barr-Rosin.

*6. Energy consumption / saving*
Primary energy use: 750 kWh/ton or 2700 kJ/kg of evaporated water. 70 – 90% of the energy can be recovered.

*7. Emission reduction*
No direct emissions to the environment. Emissions appear in the steam condensate.

*8. Operation experiences*
Many installations in long term operation. Pilot testing is possible.

*9. Reasons in favour or against superheated steam drying*

Short residence times are possible, 5 – 60 s.

Drying in SHS can often be combined with heat treatment for: increasing by-pass protein in cattle feed, stripping chemicals, sterilisation, quality improvement.

*10. Other remarks or supplements*

| **Name:** | **Date:** |
|---|---|
| **Dr. A. Lehnberger, Dr. L. Kerll, BMA** | **12 January 2004** |

*BMA fluidised bed superheated steam dryer*

**Questionnaire**

*1. Products that are dried with superheated steam*
Sugar beet pulp

*2. Industrial sector(s) applying superheated steam drying*
Sugar sector.
Also possible, not yet applied, for grain swill, fruit and vegetable residues.

*3. Throughput / evaporation capacity*
25 – 56 ton water evaporation /h, depending on size and temperature of primary energy source that is available, like high pressure steam.

*4. Drying system used, principle of dryer*
Fluidised bed superheated steam dryer with fluidisation in successive vertical columns. The product is transported upwards in each column and falls into the next column. Input and output are realised by means of sluices. Pressure inside the dryer is approximately 3 bar.

*5. Drying system used, supplier of dryer*
BMA Germany now has the rights for the sugar industry. Before this system was sold by NIRO Denmark.

*6. Energy consumption / saving*
Overall energy savings 85 – 90% by using al the produced steam in the sugar production process.

*7. Emission reduction*
Emission reductions of $CO_2$, $SO_2$ and $NO_x$ are in the order of 89%. Dust emissions are reduced with 93%.

*8. Operation experiences*
Problems used to be with the sluices, “cellenrad”, with respect to jamming, wearing and thus reduced availability. Now they are solved by better control of the pressure to tighten the flaps of the sluices.

*9. Reasons in favour or against superheated steam drying*
The completely closed dryer reduces emissions of smell and dust. The quality of the dried sugar beet pulp for feed is better than with conventional drying because

no oxidation occurs and there is no contact between combustion gases and product. Less noise, closed process, and no fire hazard.
The condensate that is fouled with odour components and dust is cleaned in the water treatment plant.

*10. Other remarks or supplements*

| **Name:** | **Date:** |
|---|---|
| **Stephan Gerl, Fa. Eirich** | **19 December 2003** |

*Eirich mixing SHS dryer*

**Questionnaire**

*1. Products that are dried with superheated steam*
Sludges, with recoverable heavy metals, desulphurisation sludges, ferrites, brake lining, coating sludges.
Pilot experiments with: catalysts, pigments, wash powder additives

*2. Industrial sector(s) applying superheated steam drying*
Chemical industry, waste processors.

*3. Throughput / evaporation capacity*
25 – 2500 kg water evaporation/h; up to 4 – 5 tons/h solvent evaporation, with superheated solvents.

*4. Drying system used, principle of dryer*
SHS indirectly heated with gas/oil (> 500 kW) or electric (< 250 – 500 kW). SHS temperatures 450 °C at the input to 120 - 150 °C at the output.
Normal operation at 800 – 1000 mbar, if necessary for product temperature, down to 50 mbar is possible (decreasing throughput).

*5. Drying system used, supplier of dryer*
Fa. Eirich from Germany, 11 to 12 SHS dryers sold.

*6. Energy consumption / saving*
Energy use: 1 kW of gas delivers 1 kg/h water evaporation, 3600kJ/kg water evaporation; an important reason for choosing SHS drying. There is only 1 application with partly recovery of condensation heat for room heating. At other applications the steam is condensed and removed. Eventual non condensables are after burned in a burner.

*7. Emission reduction*
Not so important.

*8. Operation experiences*
Good, continuous operation for 20 – 30.000 hours.
Corrosion must be taken care of. Often dust removal in the circulating steam necessary.

*9. Reasons in favour or against superheated steam drying*
Energy saving, quality higher (including agglomeration, this dryer can also form agglomerates, an important aspect). No product corrosion, oxygen free.

*10. Other remarks or supplements*
An apparatus that does more then just drying, reason why investment costs are quite high. Only the SHS does not contribute much to this process. The vacuum systems increases the price.

| **Name:** | **Date:** |
|---|---|
| **Folkert Kunzmann, Moenus Artos Textilmaschinen GmbH** | **19 December 2003** |

*Moenus textile dryers*

**Questionnaire**

*1. Products that are dried with superheated steam*
Dyed textiles, all kinds of textiles, wool, lycra, polyesters, etc.

*2. Industrial sector(s) applying superheated steam drying*
Textile finishing, 2 applications jet, 1 in full operation, 1 starting up.

*3. Throughput / evaporation capacity*
95 – 380 kg water evaporation /h.

*4. Drying system used, principle of dryer*
After dyeing, in a foulard, a gas fired IR heater at 780 °C is used for controlled pre drying. The textile web enters the steam atmosphere through a vertical slot. The SHS is at 180 °C and very fast heating of the coated web to 100 °C occurs. These circumstances are ideal for fixation of the dye. In the SHS section the steam is recirculated over indirect heater, no steam bleed, no heat recovery (jet).

*5. Drying system used, supplier of dryer*
Moenus Artos Textilmaschinen GmbH from Germany.

*6. Energy consumption / saving*
No attention for energetic aspects until now. Probably at some products the fixation unit can be cancelled, resulting in energy savings.

*7. Emission reduction*
Less chemicals necessary. Chemicals appear in the steam.

*8. Operation experiences*
First unit in operation in Brazil, trouble-free operation.
Another unit in Germany is starting up.

*9. Reasons in favour or against superheated steam drying*
Combination with fixation, possibly also a combination with bleaching.

*10. Other remarks or supplements*

| **Name:** | **Date:** |
|---|---|
| **Graham Bird, Th. Stubbing, CDS Group / Heat-Win Limited, UK** | **17 December 2003** |

*Airless dryers*

**Questionnaire**

*1. Products that are dried with superheated steam*
Ceramic shapes, sanitary ware, tableware, bricks, insulators, ceramic powder colour slurries, meat and bone meal.

*2. Industrial sector(s) applying superheated steam drying*
The ceramic and meat processing industries.

*3. Throughput / evaporation capacity*
Up to 1000 kg water evaporation /h.

*4. Drying system used, principle of dryer*
Atmospheric SHS drying, both batch and continuous, with fan-powered recirculation of indirectly heated SHS generated from the moisture in the material being dried. Airless dryers consist of an airtight dryer construction, where in incoming and outgoing product come and leave from the open bottom. Stratification of the lighter SHS prevents leakage of the steam.

*5. Drying system used, supplier of dryer*
CDS, Ceramic Drying Systems Ltd.

*6. Energy consumption / saving*
The primary energy consumption of airless dryers is between 3.5 and 4.0 MJ/kg of moisture evaporated. Up to 80% of that consumption can be reused by condensation of the steam.

*7. Emission reduction*
Emissions appear in the condensate or as a small stream of non-condensables that can be after burned.

*8. Operation experiences*

*9. Reasons in favour or against superheated steam drying*
Increased drying speed due to the avoidance of hot air dryers' evaporation-inhibiting saturated air boundary layer. Improved output quality due to the avoidance of product oxidation.

Additional capital costs in making the machines airtight and providing them with indirect heaters.

*10. Other remarks or supplements*

| **Name:** | **Date:** |
|---|---|
| **Dr. Wilfried Rähse, Henkel KgaA Düsseldorf** | **17 December 2003** |

*Henkel SHS spray dryer*

**Questionnaire**

*1. Products dried with superheated steam*
Washing powders

*2. Industrial sector applying superheated steam drying*
This is a unique, self developed SHS dryer, in operation since 1994.

*3. Throughput / evaporation capacity*
4 – 6 ton water evaporation/h.

*4. Drying system used, principle of dryer*
Spray tower, atmospheric, 350 – 120 °C, $O_2$ << 1%.

*5. Drying system used, supplier of dryer*
Own engineering and manufacturing.

*6. Energy consumption / saving*
Heat recovered by condensation at 100 °C for heating up water, used for heating of the buildings etc. (the whole plant). In summer heat is cooled away.

*7. Emission reduction*
This was the main reason for development, in the middle of densely populated area (Vienna) where odour and a white plume were unacceptable. Now there is nothing to smell and see.

*8. Operation experiences*
Good

*9. Reasons in favour or against superheated steam drying*
Safety (explosions, fire), no oxidation.
Higher product temperatures leading to stickiness, less flexible, during product change the steam atmosphere has to be replaced by air first.

*10. Remarks*
Will be considered at other places within Henkel when problems concerning environment arise.

| **Name:** | **Date:** |
| --- | --- |
| **Kees van 't Land, ex-AKZO Nobel, The Netherlands** | **25 February 2004** |

**Questionnaire**

*1. Products that are dried with superheated steam*
SHS drying is considered for all AKZO Nobel products, salts, catalysts, pharmaceuticals, pigments, fibres, etc. No SHS dryers were selected, among others because the throughputs are generally to small to justify the higher investment costs. Energy uses are a relatively small part of the overall costs.

*2. Industrial sector(s) applying superheated steam drying*

*3. Throughput / evaporation capacity*
Generally to small for economic applications.

*4. Drying system used, principle of dryer*

*5. Drying system used, supplier of dryer*

*6. Energy consumption / saving*

*7. Emission reduction*

*8. Operation experiences*
In and output devices like rotary valves stay critical parts of the SHS dryers.

*9. Reasons in favour or against superheated steam drying*
Safety, explosion and fire risk prevention. Product quality, can be better or worse. SHS drying has to be more integrated in the whole processing, energy recovery, making the operation more complex.

*10. Other remarks or supplements*

| **Name:** | **Date:** |
|---|---|
| **Mr. J. Zuur, Avebe, The Netherlands** | **17 February 2004** |

*SHS drying of fibres and proteins*

**Questionnaire**

*1. Products that are dried with superheated steam*
Potato fibres, potato washing water to regain proteins.

*2. Industrial sector(s) applying superheated steam drying*
Potato processing, starch production.

*3. Throughput / evaporation capacity*
Pilot scale experiments.

*4. Drying system used, principle of dryer*
Both the GEA pneumatic Dryer and the BMA/NIRO fluid bed dryer have been investigated. No SHS dryer has been installed.

*5. Drying system used, supplier of dryer*

*6. Energy consumption / saving*
The energy saving potential was an important issue in the considerations. The best energy integration is possible when the dryer operates at the pressure of the existing steam system. With fouling of the steam reboilers might be necessary.

*7. Emission reduction*

*8. Operation experiences*
Glazing of starch above 60 °C. Stickiness of starch and starch containing fibres is a problem. In and output devices stay critical in the operation.

*9. Reasons in favour or against superheated steam drying*
The application is also dependent on the developments in the market for fibres and proteins.

*10. Other remarks or supplements*

**Name:** **Date:**
**Mr. R. van der Poel, Bunge (former Cereol)** **25 February 2004**
**Mannheim, Germany**

*GEA Exergy Barr-Rosin Dryer / steam processor*

**Questionnaire**

*1. Products that are dried with superheated steam*
Rape seed and sunflower seeds.

*2. Industrial sector(s) applying superheated steam drying*
Vegetable oil and base material production for animal feed.

*3. Throughput / evaporation capacity*
100 ton/h throughput. The drying capacity is not relevant, because thermal processing is the first goal of the process. Some 2.5 tons of water is evaporated per hour, but this is not the intention of the process.

*4. Drying system used, principle of dryer*
Pneumatic superheated steam dryer with multiple vertical pipes connected with pipe bends. The steam transports the product pneumatically through the dryer. The steam is reheated with heat exchangers external to the pipes. The pressure inside the dryer is 2.5 bar absolute.

*5. Drying system used, supplier of dryer*
GEA Exergy Barr-Rosin Dryer / steam processor.

*6. Energy consumption / saving*
The energy consumption of not directly known, but it will be limited because no relevant drying has to take place. The small amount of water that is evaporated is removed from the dryer directly to the atmosphere. No condensation is applied, so no recovery of energy.

*7. Emission reduction*
This was no argument at all.

*8. Operation experiences*
In the beginning of the start up some problems were encountered with the sluices, but not very much. The main problems during the start up had to do with the changing product qualities that made adaptation of the further processing necessary.

*9. Reasons in favour or against superheated steam drying*

For the oil containing seeds better product qualities can be reached, the main reason for installing the equipment. For feed components, the qualities increased with respect to the application in animal feed.

*10. Other remarks or supplements*

| **Name:** | **Date:** |
|---|---|
| **Mr. W. Derksen, Rijssen, The Netherlands** | **29 January 2004** |

*GEA Exergy Barr-Rosin Dryer*

***Start-up summer 2000***

**Questionnaire**

*1. Products dried with superheated steam*
Sawdust and wood fibre for the production of composite material profiles and boards.

*2. Industrial sector applying superheated steam drying*
Wood processing industries.

*3. Throughput / evaporation capacity*
2 ton/h of wood, from 15 to 0,5% humidity, evaporation capacity: 300 l/h.

*4. Drying system used, principle of dryer*
Exergy Dryer with 2 rotary sluices. Absolute pressure 1,5 bara, steam temperatures over 200 °C.

*5. Drying system used, supplier of dryer*
GEA Barr-Rosin

*6. Energy consumption / saving*
A 100 kWe CHP with diesel engine is present. The diesel exhaust gases are used to heat up the SHS in a heat exchanger. If necessary additional heating with electricity from the CHP is applied.
No heat recovery is applied. This would be possible from condensate and cooling water of diesel engine.

*7. Emission reduction*
Dust, only limited in condensate. Condensate contains resins and oils, to sewage.

*8. Operation experiences*
Temperature and pressure are controlled by the ingoing and end moisture content of the wood.

*9. Reasons in favour or against superheated steam drying*
Explosion and fire limitation.
No dust emission.
Low end moisture products.

*10. Other remarks or supplements*

For a possible next dryer, a paddle dryer may be a better alternative (partly the same advantages as SHS drying).

How long do the pipes of this SHS dryer (13 m) stand the repeated expanding and shrinkage?

**Name:**
**Prof. J. Vasseur, ENSIA, MASSY France**

*SHS spray-drying*

**Questionnaire**

*1. Products that are dried with superheated steam*
Potentially, all spray dried liquids.

*2. Industrial sector(s) applying superheated steam drying*
Food, starch.

*3. Throughput / evaporation capacity (ton/h / ton water evaporation/h)*

*4. Drying system used, principle of dryer*
Spray dryer.

*5. Drying system used, supplier of dryer*

*6. Energy consumption / saving*

*7. Emission reduction*

*8. Operation experiences*
You have to make practical tests for each product about stickiness, and think to the way of cooling the product after drying.
Starch gets gelatinised.
As the product temperature in SHS is higher than in air drying, the stickiness may be a problem.

*9. Reasons in favour or against superheated steam drying*

*10. Other remarks or supplements*
The industrial development of the pilot SHS spray dryer is given to Techniprocess.

**Name:**
**Mr. M. Sionneau, Techniprocess, France**

*SHS spray-drying*

**Questionnaire**

*1. Products that are dried with superheated steam*
Chemicals, starch and concentrated industrial waste.

*2. Industrial sector(s) applying superheated steam drying*
Food, chemical and pharmaceutical industries.

*3. Throughput / evaporation capacity (ton/h / ton water evaporation/h)*
Pilot plant spray dryer with an evaporation rate of 50 kg/h at 700 °C.

*4. Drying system used, principle of dryer*
Spray dryer.

*5. Drying system used, supplier of dryer*
Techni Process is an engineering firm for the food, chemical and pharmaceutical industry. We expect development of this technology in chemical and starch industry and drying of concentrated industrial waste, but we don't yet realise test. We are looking for industrial cooperation.

*6. Energy consumption / saving*
Pilot testing: 1.2 kg of steam for 1 kg of water evaporated.

*7. Emission reduction*

*8. Operation experiences*

*9. Reasons in favour or against superheated steam drying*

*10. Other remarks or supplements*
High evaporation rate possible.

**Name:**
**Prof. A.S. Mujumdar, National University of Singapore**

**Questionnaire**

*1. Products that are dried with superheated steam*
Wood pulp, hog fuel, beet pulp, wood

*2. Industrial sector(s) applying superheated steam drying*
Paper, Foods, Wood, Coal (pulverised)

*3. Throughput / evaporation capacity (ton/h / ton water evaporation/h)*

*4. Drying system used, principle of dryer*
Flash, fluid bed; batch kiln (low pressure for wood drying)

*5. Drying system used, supplier of dryer*

*6. Energy consumption / saving*
In principle low- but depends on whether exhaust steam is used elsewhere in process

*7. Emission reduction*
Yes. Condensed steam may have heavier COD, BODs e.g. in vacuum steam drying wood/ flash drying pulp etc.

*8. Operation experiences*

*9. Reasons in favour or against superheated steam drying*
Must be air-tight; more capital-intensive. Other well-known advantages.

*10. Other remarks or supplements*
Many lab/pilot scale studies exist. E.g. spray drying in steam, impingement drying of paper. etc.

**Name:**
**Prof. S. Devahastin, King Mongkut's University of Technology Thonburi, Bangkok, Thailand**

**Questionnaire**

*1. Products that are dried with superheated steam*
Shrimp, pork, bamboo shoot, paddy, potato, carrot (low-pressure unit)

*2 Industrial sector(s) applying superheated steam drying*
Food and agricultural industries.

*3. Throughput / evaporation capacity (ton/h / ton water evaporation/h)*
200 kg/h (paddy)

*4. Drying system used, principle of dryer*
Fluidised bed dryer, cabinet dryer.

*5. Drying system used, supplier of dryer*
Pilot scale unit, locally made.

*6. Energy consumption / saving*

*7. Emission reduction*

*8. Operation experiences*
About 3 years (both with near-atmospheric and sub-atmospheric pressure ranges)

*9. Reasons in favour or against superheated steam drying*
Favour: High product quality
Against: Difficulty to recover/reuse the exhausted steam

*10. Other remarks or supplements*
More international collaboration on SHS drying research would be beneficial.

**Name:**
**Prof. Dr. M. Kind, University of Karlsruhe, Germany**

**Questionnaire**

*1. Products that are dried with superheated steam*
Wood chips, potassium salt and powdery chemicals, dried in vacuum contact dryers.

*2. Industrial sector(s) applying superheated steam drying*
Wood industry.

*3. Throughput / evaporation capacity (ton/h / ton water evaporation/h)*

*4. Drying system used, principle of dryer*

*5. Drying system used, supplier of dryer*
Laboratory SHS dryer, self-made.

*6. Energy consumption / saving*

*7. Emission reduction*

*8. Operation experiences*

*9. Reasons in favour or against superheated steam drying*
Against: SHS is subjected to unwanted condensation. In particular problematic is the continuous operation, with the necessary ports for continuous feed and product removal.