# Renewable energy and energy efficiency for warm air production in food drying

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**Abstract:** Drying of food is most commonly achieved by blowing warm air in contact with the products, at temperatures below 90ºC. The warming up of air is often made with fossil combustibles or even electricity. There are several ways to retrofit such plants into hybrid systems associating renewable energies and to improve the efficiency of energy use.

**Keywords:** drying, energy, renewable energies, solar thermal energy, wood burners, solar energy, cogeneration, heat exchangers, energy efficiency, water evaporation.

## 1. Overview

### 1.1. Goal and Scope

#### History

Several technologies were investigated (solar water and air collectors, wood burners, CHP units, heat exchangers). The project's objective is to provide a general guide and method for the assessment of cases of small manufactures of food processes requiring warm air for drying.

#### Summary of the base case

The base case is an existing drying process line using gas, oil or electric heating for warm air production, with :

- inflowing air is at ambient condition.
- the desired air temperature for the process is between 50 and 95ºC, with flows below 5000 kg of dry air / hour, for power demands up to 100 $kW_{th}$.
- working at atmospheric pressure.

### 1.2. Drying

#### Drying with warm air

Warming up air increases its capacity to absorb water. To avoid cooking the different interesting nutriments (vitamins, starch ..) the temperature must be limited during the drying process, with a maximum of 40 to 90ºC, depending on the product. [3]

#### How much drying ?

The main purpose of drying food product is to ensure proper conservation through an extended period of time. Biologic activities of ripening and rotting cease when the water content reaches down typical levels of 10-15% humidity (mass in dry base).

## 2. Case Study : the Troki manufacture

The faculty of Witzenhausen hosts a small manufacture called *Troki*, whose business is drying and selling fruits and vegetables. The company was started in may 2007 by two former students of Pr. Hensel.

### 2.1. Financial situation

The company is very young. They obviously have no plan to do investments that have a long pay-back time.

#### Current prices of energy

Electricity: 17c€ / $kWh_e$

Natural gas: 8,19 c€t / kWh, + 9,29 € /month.

Energy account to 5% of the total production costs (excluding labour).

### 2.2. Facilities

Since June 2008, they use 2 driers manufactured by Innotech and fed in heat by gas burners.[4]

One of the slopes of the building's roof has a mildly favourable position for solar energy.

#### Efficiency of the drying process

The efficiency of the heat use was estimated at 48%. [see *§3.2.*]

### 2.3.Production process

The production is extremely intermittent, with the driers running usually from the afternoon till the middle of the night, and on an irregular schedule. This makes the forecasts of the usage of solar energy difficult.

### 2.4.Difficulties to assess demand and do economic calculations

There are no precise logs of past production, 2 driers of different sizes, with no statistics of how often they are respectively used, and no long-term view of future production.

### 2.5.Functioning of the driers and heaters

#### Description

Each drier has 2 fans, one for air recirculation inside the drier, which runs continuously, and another for air extraction, which runs intermittently. The driers operate in cycles of 2 phases (recirculation / extraction), controlled by an external processor in charge of monitoring both the drier and the heater.

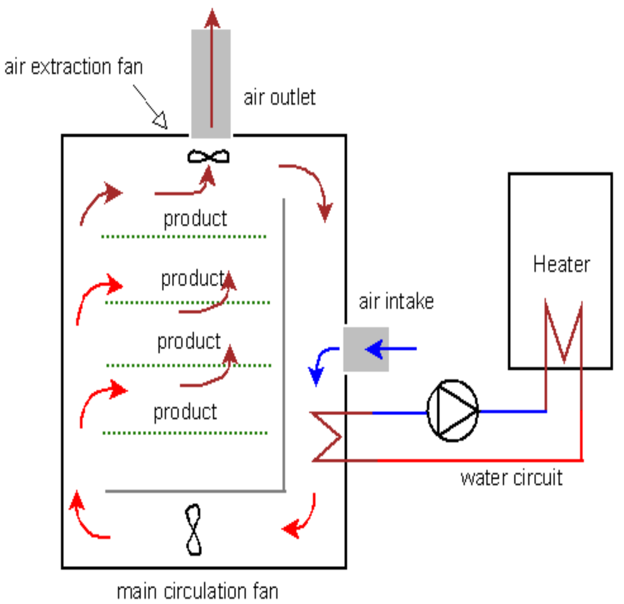


*Diagram 1. Air extraction phase of the drier*

## 3. Assessment of needs

### 3.1.Air flow

It is a key factor for the design of many systems (air solar collectors, heat exchangers), and yet it is difficult to measure.

### 3.2.Efficiencies

Two important values of efficiency must be discriminated for a proper assessment of the energy demand :

- Heat production efficiency (burners)
- Heat use efficiency (driers)

### 3.3.Global thermal energy demand

The annual energy demand can be evaluated by the following methods :

- Fuel consumption
- Tonnage of production and average global efficiency of the process
- Air flow and temperature rise (least precise)

### 3.4.Fluctuations of the demand

During the recirculation phase, the heaters are completely idle. During the extraction phase, they run at full power most of the time.

## 4. Wood burners

### 4.1.Comparison with gas or oil burners

Burning of fluid combustibles is much easier to regulate than burning of solid ones, as they have a significant inertia.

### 4.2.Combustible

#### Marketed combustibles

The suitable type of combustibles for automated facilities are wood pellets and wood chips. Wood logs burners usually require manual interventions.

#### Residual biomass from the process

Some residual biomass may be available as by-product of the drying process (i.e. for Troki: cherry stones), and can be used as combustible. Those by-products may account for 20% of the combustible consumption. It limits the available choice of burners and may lead to technical complications. [9] When possible, it is better to use them in other applications with lower technical requirements (i.e. home heating furnaces).

## 4.3. Heat buffering in water storage

**Sizing**

It must be sized to match the following criteria :

- Possible emergency stops
- Power surges [see §3.4.]
- Response time of burner

**Design**

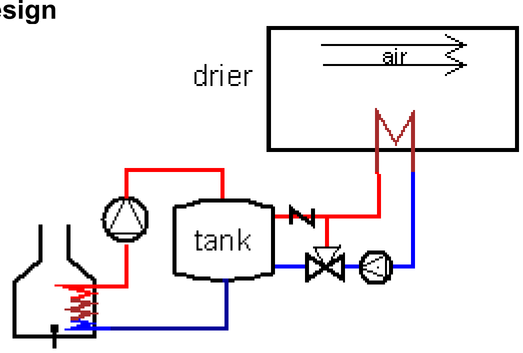


*Diagram 2. Heat buffering using a 3-ways valve.*

In this configuration, the tank acts as a secondary heat source.

- The burner and pumps run continuously, controlled by the temperature in the buffer.
- The 3-ways valve is controlled by the air temperature in the drier.
- The anti-return valve prevents the fluid from entering back into the tank.
- This is a simple control as the secondary heat source is either 'on' or 'off'.
- There can be one central burner and tank, with dispatches over several driers.

# 5. Solar energy

## 5.1. Water collectors

**Advantages and drawbacks**

- Widely implemented technology.
- Storage is possible, although it leads to higher costs and requires a lot of space.
- The temperatures that can be achieved is often too low for standalone systems or hybrid systems with 2 heat sources on the same heat channel (drying temperatures up to 85ºC).

**Main problem of water solar collectors in hybrid systems**

Water solar collectors usually achieve usually temperatures in the range of 60-70ºC. This means the temperatures of air that can be achieved using the hot water as heat source through a heat exchanger are in the 50-60ºC range.

## 5.2. Air collectors

**Advantages and drawbacks**

- The design and installation are cheaper and easier than with water collectors (no problems of freezing or over-pressure).
- No storage is possible. Drying must therefore occur during day time. This requires precise assessment of the demand curve every month.

**Types of collectors**

- Glazed solar collectors
- Transpired solar walls (or roofs)

Transpired solar walls are a simpler system. Its technical performances are not as good as glazed collectors, and achieving high temperatures is difficult. However, it makes up for it with its price, as it is very cheap, and is suitable for pre-heating of air before admission.

**Design and sizing**

The key factor for the sizing is the air flow imposed by the drier :

- Efficiency decreases with temperature difference, thus with a lower flow.
- Head losses increase with flow.
- The air flow is set by the drier fan, the thermal power collected is to be calculated consequently.

**Regulation**

The obtained temperature at the exit of the collector of the must not exceed the drying temperature in the process. This compels to have a regulation system (thermovalve) or to size the system small enough so that the temperature never rise above this limit.

# 6. Improving the energy efficiency

The energy efficiency of the process line can be improved by:

### 6.1. Preventing losses

- Losses of air
- Losses of heat

### 6.2. Adjusting the parameters of the process

#### Air temperature

"The warmer is the better" , as long as it is not detrimental to the product quality : the drying goes faster, resulting in less heat losses. Beside, the amount of energy required to warm up air over the quantity of water that can be evaporated decreases with temperature.

#### Flow speeds

Flow speeds must be adjusted for good heat transfers.

#### Duration of the cycles of functioning

### 6.3. Recovering waste heat using plates heat exchangers (HE)

The flow of outgoing air is wet but still much warmer than the incoming air. HE may allow to recover part of the heat while keeping out the humidity.

HE have a good pay-back time (1-5 years), and they are compatible with any kind of heating. They may also lead to a down-sizing of the rated power of heating system.

#### Design and sizing

The expected efficiency is 70% of the ingoing flow and 35% of the heating requirements.

#### Pressure drop

In retrofitting, it is very likely that adding a HE requires adding a new fan or over-sizing the old one.

## 7. Cogeneration of heat and power

### 7.1. Analysis

- the range of temperatures allows to use the waste heat from both exhaust gases and cooling liquid.
- micro CHP units are available at rated powers as low as 1 $kW_e$ / 12 $kW_{th}$ [8]
- the technology is simple enough to be maintained by a company whose business is not energy supply.
- there are available CHP units working with diesel oil, natural, propane, biogas.

However,

- Fluctuations of demand are a problem, similarly to operations wood burners. [see *Heat buffering in water storage* p.3]. Yet, cogeneration units can be stopped immediately in case of emergency.
- Micro-CHP Stirling engine units have lifetimes of 40 000 hours which is too long for many projects. [7]
- Under the german feed-in tariffs, to be a really interesting investment, the electricity should be used on site or produced with a renewable fuel. Existing biogas CHP plants can sell off their heat at interesting prices to benefit from better feed-in tariffs.

## 8. Conclusion

### 8.1. Distinguished technologies

- Transpired solar walls
- Heat exchangers
- Cogeneration when the electricity can be used on the site or produced from a renewable fuel.

### 8.2. Compatibility of the different solutions

- Transpired solar walls + HE.
- CHP + HE if the demand does not fluctuate too much (using a HE leads to downsizing the CHP unit).

### 8.3. The Troki case

The lack of data on the production did not allow proper calculations of profitability. Besides, given the financial situation of the company, it is unlikely they will invest soon.

Yet, the study was not pointless for them. This study gave them the tools and shall allow them to know what data they need to measure in order to do those calculations with acceptable accuracy until they reach a stable situation.

### 8.4. Innotech

Following this study, the director of Innotech, Herr Esper will study including heat exchangers in their design of driers.

## 9. Acknowledgements

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