The drying of fish and utilization of geothermal energy; the Icelandic experience

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Abstract

This paper is about industrial uses of geothermal energy for drying of fish products. Drying is an ancient method for preservation of foods, the main purpose of which is to prolong the preservation time. In order to dry food, an external source of energy is needed to extract water from it. The use of geothermal energy in fish processing to replace oil and electricity offers great potential. In the fishing industry, geothermal energy has mainly been applied to indoor drying of salted fish, codheads, small fish, stockfish and other products. In this paper an emphasis is placed on drying fish and associated processes, and how geothermal energy can be used to substitute oil or electricity. The Icelandic Fisheries Laboratories have been experimenting with different methods of drying and several drying stations have been designed for indoor drying of fish products. Today there are around twenty companies in Iceland, which are drying fish indoors using electricity and/or geothermal energy. There are unexplored possibilities in utilization of geothermal energy in regions where good harbors are located in geothermal areas.

Keywords: *air drying, geothermal, byproduct, pelagic fish.*

1 Introduction

In recent years, the annual world production of dried, unsalted fishery products has been 350,000 tons, but the total world production of dried fish is 3,140,000 tons. Production of stockfish is about 10,000 tons; the main producers being Iceland and Norway, the biggest producers of the other dried products are countries in Asia and Africa. The annual export of dried codheads from Iceland is about 15,000 tons, mainly to Nigeria, where they are used for human consumption. Dried petfood is a new industrial production in Iceland and a growing industry, the annual production being about 500 tons. There has been much interest in Iceland in producing dried fish for human consumption from the various small fish species, like blue whiting and low fat capelin. The annual production of dried seaweed and kelp in Iceland is about 4,000 tons.

The use of geothermal energy in fish processing, instead of oil and electricity, has many advantages. In the fishing industry, geothermal energy has mainly been applied to indoor drying of salted fish, codheads, small fish, stockfish and other products. The first companies in this field were founded 25 years ago and now there are more than twenty companies. Most companies use geothermal energy for drying codheads and collarbone. In 2001 the consumption of hot water was about 2 million tons or about 550 TJ. Experiments have been made on the use of geothermal steam for fishmeal processing, but the company involved is no longer in business. It also seems to be possible to utilize geothermal steam for freeze-drying. There are unexplored possibilities in utilization of geothermal energy in regions where there are good harbors located in geothermal areas.

Most of the research on the drying processing in this field was carried out for about fifteen years ago. At this time the main work in the trails was carried out to find out the best drying parameters to obtain the best products qualities and to optimize the drying processes. In the trails it was to find out the air speed, air temperature, air humidity, product loading on each tray and the size of the drying tunnel. The latest trails in this field are to find out the influence raw materials has on the products qualities and the stabilization of the product with the different storage parameters.

2 Drying

Drying means that water is extracted from a substance, usually by heating. During drying, there are two things of primary importance, i.e., the heat transfer that causes the evaporation of water and the mass transfer of the evaporated water through the substance and subsequently the removal of moisture away from the surface of the substance itself. The main purpose in drying is to prolong the preservation time of the product. In short, deterioration of food is caused either by microorganisms or chemical processes. In drying, both of these processes are slowed down and finally stopped altogether, depending on how far the drying is carried out, with one exception, which is oxidation. The drying time is generally divided into two periods, period of constant drying rate and a period of falling drying rate. The former period is characterized by the surface of the substance being entirely saturated with moisture at the wet-bulb temperature of the air. The air velocity, temperature and the level of humidity control the drying rate. During the period of falling drying rate, the surface of the substance is already dry but the evaporation occurs inside the fish flesh. Now the air velocity has less effect and the speed of the drying process is mainly dependent upon the resistance against the water vapour flow to the surface of the substance. At the end, the drying process stops entirely and the moisture content of the fish at that point is called equilibrium humidity. Equilibrium humidity is primarily dependent on the degree of humidity of the air and to some extent on the temperature.

3 Utilization of geothermal energy for drying

In Iceland, indoor drying has been tested in regions where geothermal energy is to be found. The reason is that the cost of oil or electricity for heating of the drying air during the drying process is considerably higher than the cost of hot water or geothermal steam. It is therefore more cost-efficient to locate the processing near inexpensive hot water and steam sources and collect the raw material and transfer it to the processing plant.

The price of energy for heating varies much from one energy source to another and from one location to another. The price of oil has fluctuated but the price of hot water and electricity has changed less, although it tends to follow the price of oil. (See Figure 1).

Figure 1 shows the energy costs of heating air for drying one kilogram of dried codhead in Iceland. The prices are extrapolated using the price in January of 2003 and the main assumptions are that the energy required for evaporating one kilogram of water in the drying process from a substance is about 5,800 kJ (1,400 kcal), the efficiency of oil boilers is estimated at 90%, co-efficient of performance of heat pumps 2.5, and it is assumed that the hot water is cooled from 80°C to 30°C (Arason, 2001).

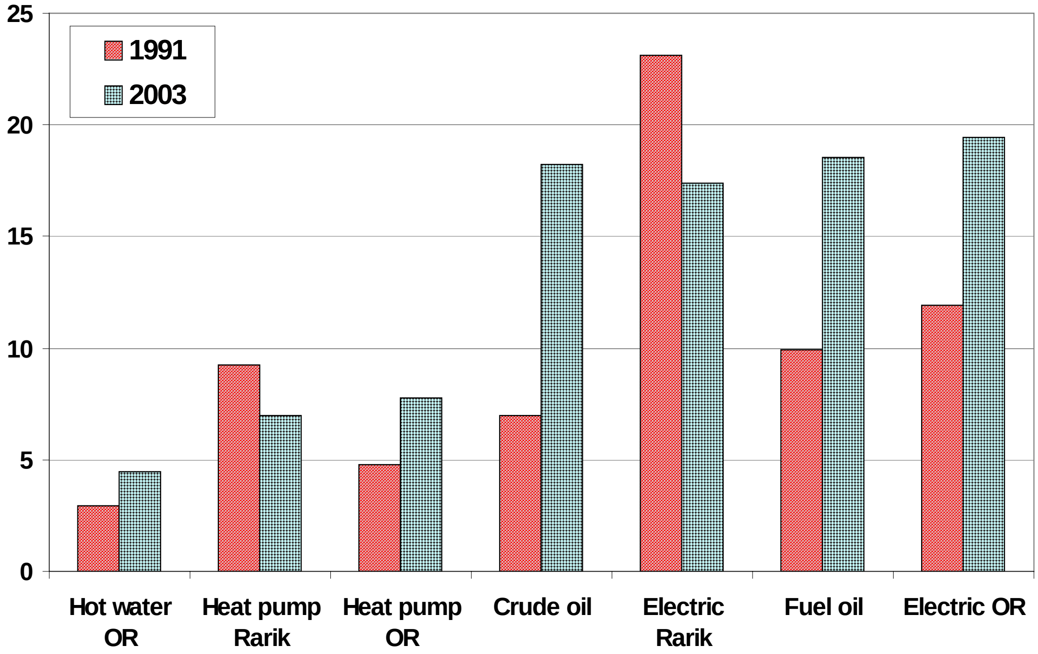

Figure 1: Comparison of prices for different types of energy for heating, ISK for drying one kilogram of dried codhead, based on cost in January 2003 (1 USD = 80 ISK). (OR = Reykjavik Energy and Rarik = Icelandic state electricity).

4 Indoor drying of fish

Weather conditions put limits on outdoor drying in Iceland. Indoor drying of fish, such as cod-heads, or small fish, is done in such a way that hot air is blown over the fish and the moisture from the raw material subsequently removed.

It is a great advantage to be able to dry fresh raw material all year around and not to be dependent on weather conditions. Furthermore, drying indoors takes much less time, from several weeks outdoors to a few days indoors. The main advantages of indoor drying are therefore (Arason et al.,1982):

– shorter drying time
– drying all year around and regular export shipments
– the product is more consistent in quality and water content
– flies and insects are prevented from contaminating the product
– utilization of local energy sources

Cod heads were traditionally dried by hanging them on outdoor stock racks, but indoor drying was initiated 25 years ago (see Figure 2). In Iceland, the production of dried cod heads increased from 1000 tonns to about 12.000 tonns annually and this production needs 60.000 tonns of wet, fresh heads. The largest drying stations are Laugafiskur in Thingeyjarsysla, Samherji in Dalvik and Hnotskurn in Thorlakshöfn and Thorungavinnslan in Reykholar, which specializes in drying seaweed and kelp. In total, there are about 20 companies which produce air dried codhead, all of them except two using geothermal energy. One drying plant uses oil and another is using a heat pump system. A third one uses geothermal steam for drying but most companies use geothermal water. Most of the drying cabinets are constructed for batch drying and cod-heads are arranged on trays. Only two codhead drying plants and Thorungavinnslan use conveyor-belt dryers.

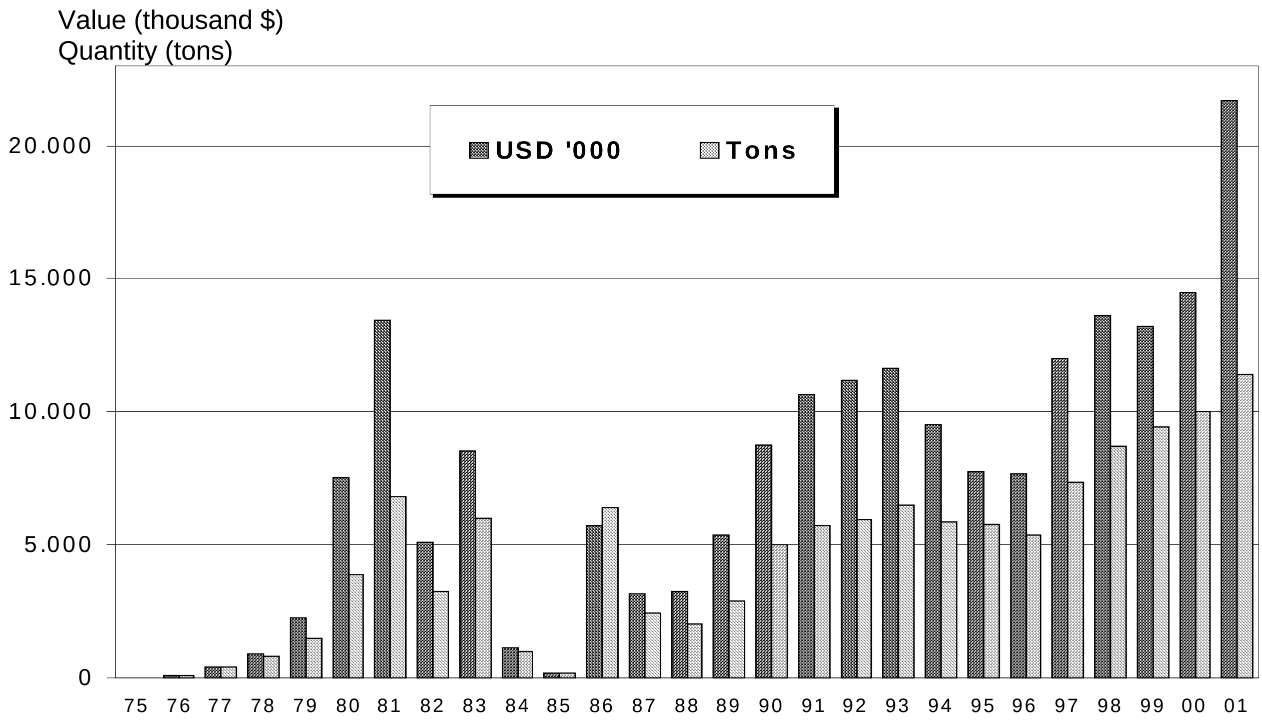

Figure 2: Quantity and value of exported cod head products from Iceland, 1975–2001.

There are also about 50 small drying plants in Iceland which produce dried fish snacks, which are very popular in Iceland. Most of the small dryers are using geothermal energy.

Full drying of cod-heads indoors has been successful and the drying is divided into two stages, primary drying and secondary drying (see Figure 3).

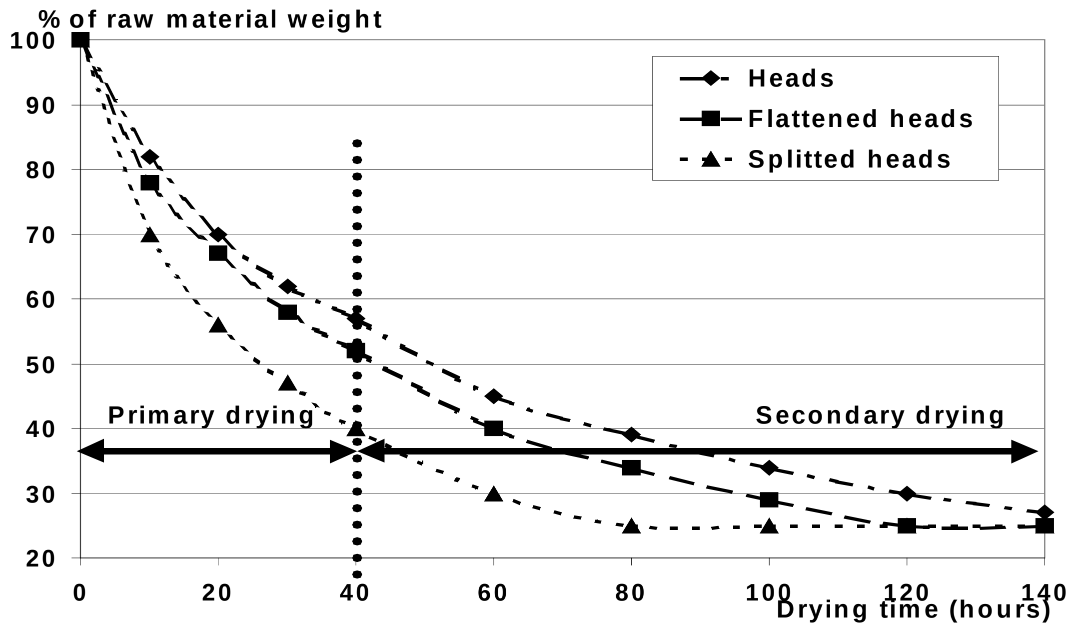

Figure 3: This figure shows how the weight of cod-heads changes with time in indoor drying. The drying is conducted in two stages, primary drying and secondary drying. The cod-heads are treated in three different ways prior to the drying.

Primary drying is done in a rack cabinet or a conveyor-belt cabinet. The rack cabinet is the most common, with cod-heads arranged in one layer on the racks where about 25 kg of heads can be arranged per square meter. The optimal conditions of the drying air are: temperature should be 18-25°C, relative humidity 20-50% and air velocity about 3 m/s. The duration is about 24-40 hours (Arason et al., 1992). The water content of the heads at the end of this stage is about 50-55%.

Secondary drying of semi-dried codheads is conducted in drying containers of l-2m^3 volume with hot air blown through. The optimal conditions are: air temperature 22-26°C, humidity 20-50% and the air velocity in a full container is about 0.5-1 m/s. The water content of the cod-heads after drying is about 15%, or the water activity of the product must be lower than 0.6, which is achieved in about 3 days in the drying container (Arason et al., 1992).

The greatest advantage gained by dividing the drying process is that relatively larger quantities of cod-heads can be placed in the secondary drying facilities than in the primary drying cabinets. The initial and operational costs of secondary drying are much lower than that of primary drying so that the production cost is lower if the process is divided.

In our experience, the best conditions for primary drying of cod head are as follows: air temperature at 25°C, airspeed about 3 m/s and air humidity about 45%. The final water content after the primary dryer is 55-60% (about 50%weight loss) and Figure 3 shows that it takes about 40 hours to reach that point (Arason et al.,1988).

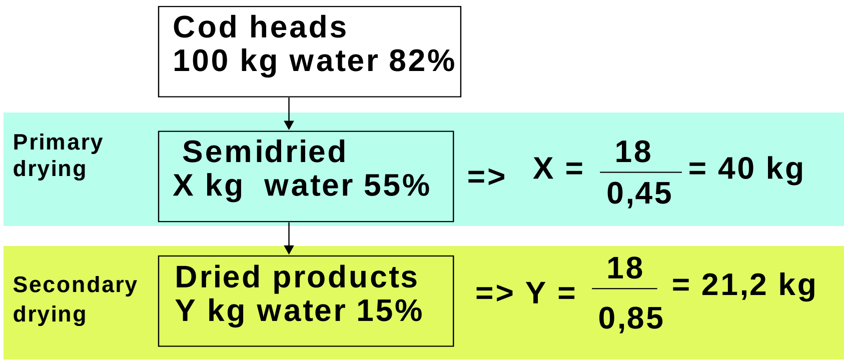

Figure 4: Flow diagram for the drying of cod heads. Percentage yield figures are given for each step.

Figure 4 shows a complete flow diagram for the drying of cod heads, including yield figures. The total drying time for splitted cod heads is about 120 hours and the yield is 21,2%. For untreaded cod heads the drying time is 160 hours.

It is also possible to extract the heat from the drying air which is either blown out or recycled. The recycling of the heat is important, in particular in drying plants located outside of the geothermal regions. The results from a preliminary study at the IFL-laboratories indicates that it is possible to save up to 35% in energy by using heat-exchangers, and up to 70% through the use of heat-pumps (Arason et al., 1992).

Chemical and microbiological tests show that there is no significant difference in the contents of stockfish, whether it is dried indoors or outdoors. There was, however a great difference in the color where the indoor dried stockfish was much darker and kept its original color better than the stock fish that was dried outdoors. These tests showed that the total drying time for stockfish indoors is about 15-25 days. It is possible to shorten the drying time of outdoor drying by a few months by transferring it indoors for secondary drying.

5 Drying small pelagic fish

The method of drying small pelagic fish is similar to drying cod-heads, where the fish is first primary dried and subsequently processed through secondary step in drying containers. Only small, low-fatty fish, such as capelin and blue whiting caught at the time of the year when the fish contains less than 5% of fat, can be used for drying (Arason et al., 1992). The fat content of capelin is less than 5% for about two weeks at the end of March, and therefore capelin intended for drying for the rest of the year must be stored. It is possible to store the capelin either be freezing or salting. In desalting, however, some of the dry material is lost, but the storage cost in salt is only one fifth to one third compared to that of freezing. Dried small fish is well suited for pet food as well as for human consumption.

The most important results regarding both blue whiting and capelin were that the fish should not be taken out of the drying cabinet (primary drying) unless the water ratio (weight of water/weight of dry matter) is down to 1.0 (50% w/w water content). Regarding the secondary drying, the fish can be taken out of the drying cabinet at a water ratio of 0.18 (15%). The temperature in the drying cabinet must not be higher than 30°C. If it is higher, the fish will be cooked and become brittle and cannot be packed as whole fish (Jason, 1958).

Regarding blue whiting, the maximum total fat content for ungutted fish seems to be around 3.5%, if it is to be used for drying (Arason et al., 1992). The fat content can vary considerably between individual fish, e.g. when measured in July it varied between 3-8% in the same catch. The reason for this is probably that blue whiting do not all migrate at the same time to the fishing grounds off the east coast of Iceland. Blue whiting must therefore be gutted prior to drying if it is caught later than in June.

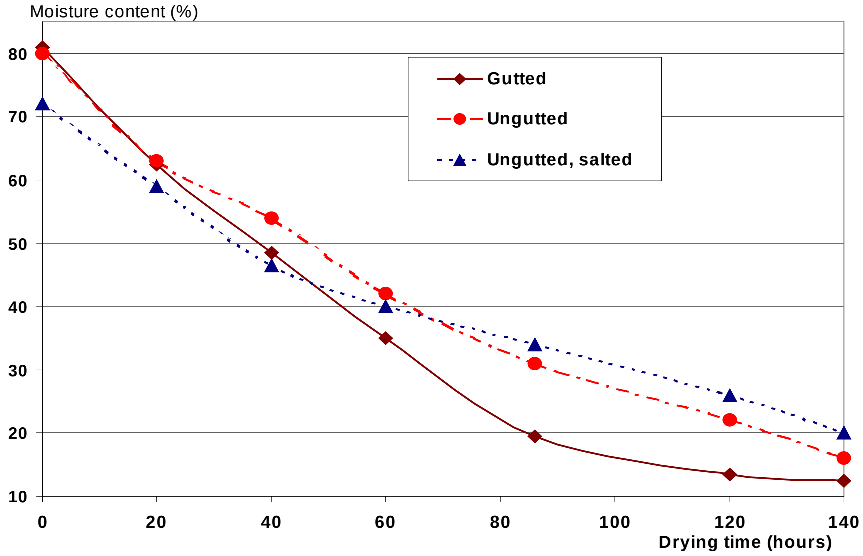

Figure 5: Drying curves for blue whiting.

Experiments were made with drying capelin in a rackdryer and a conveyor-dryer as primary drying. These experiments showed that the fat content in capelin should not be higher than 4.0% prior to drying (Arason et al., 1992). According to this, the economical catching season is about one month in Icelandic waters. Mainly male capelin is used for the drying but the female fish can also be used after spawning, at which time they contain only 2% fat. The dried male fish is, however, considered to be of better quality.

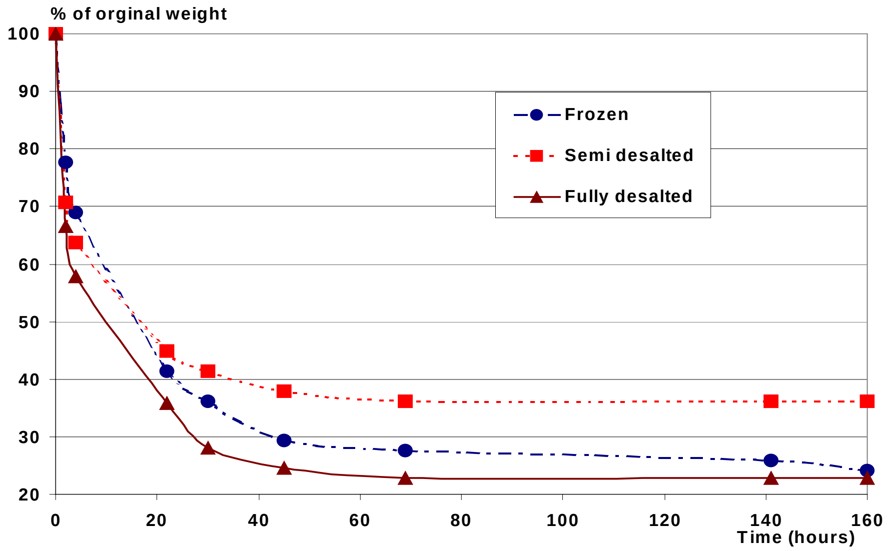

Figure 6: Drying curves for capelin. The capelin was frozen and salted before drying.

Figure 6 shows the drying curves for capelin. The curves and the drying rate for frozen and fully desalted capelin are quite similar, but the curves for the semi-desalted fish are different because part of the water is bound to the remaining salt in the capelin. (Adolfsdottir & Arason 1988).

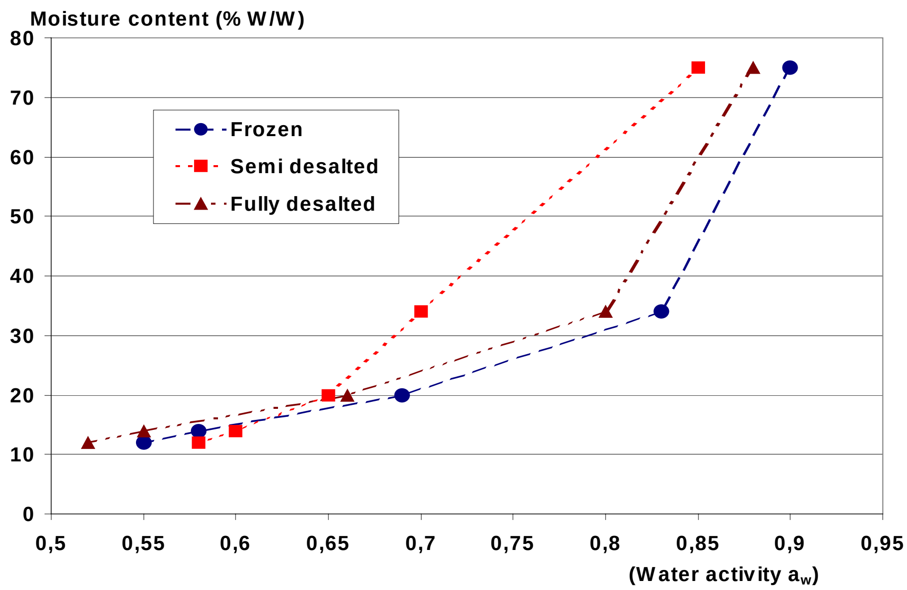

Figure 7: Relationship between moisture and water activity in dried capelin.

Figure 7 shows the drying isotherms for capelin. The isotherms for frozen and fully desalted capelin are quite similar. The water activity falls more rapidly when the water content is below 30% in the drying process. Water activity for semi-desalted capelin expectedly dropped more quickly and was about 0.7, with water content 35%.

6 Air drying equipment

Batch dryer - rack type

The most common equipment for indoor drying in Iceland is a rack cabinet, the cabinets most frequently consisting of two tunnels with a pyramid in the center. The pyramid can be moved in such a way that all the airflow is directed through one tunnel, if the cabinet is only half full. Air-valves are inserted in the inlets and recycling outlets, but the regulation of the valves is controlled by the air humidity, measured at the opening of the cabinet. A regulating valve on the hot water inlet connected to a thermometer, which is located at the same place as the humidity sensor, controls the temperature in the drying cabinet (see Figure 8).

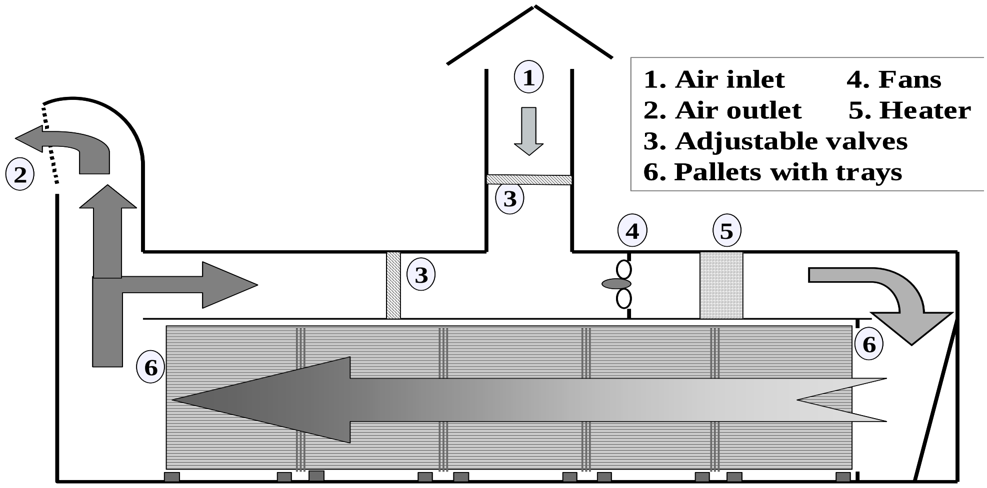

Figure 8: The construction of the rack drying cabinet.

One rack cabinet dryer with heat pumping system is in use in Iceland. The air is heated in the condenser and then blown through the cabinet. In the evaporator, the air is cooled and the moisture, which was absorbed in the cabinet, is condensed before the air is heated again in the condenser. About 40% of the energy needed for heating is supplied by electricity, but the other 60% comes through reuse of the condensing heat, which is released in the evaporator (Arason et al., 1992). The heat pumping systems can be of much use in warming where geothermal energy is not available. On the other hand, the initial capital cost is high and since there is not much experience with these types of cabinets, people have been hesitant to experiment with them.

Continuous - conveyor belt dryer

Three conveyor-belt dryers are in use in Iceland (see Figure 9). They are located with the company Saesteinn and Thorungavinnslan. One of the conveyor belt dryers is used for primary drying of cod-heads and small fish, such as capelin and blue whiting, and the other one is used to dry seaweed and kelp. Initially, the wet raw material is placed on the top belt and then the belt is left idle for about 3 hours. After that, the product is moved down to the next belt and at the same time the first belt is refilled, etc. The two lowest belts are driven at half the speed of the three top ones so that the product stays for six hours on each belt. The raw material is therefore 20-24 hours in the cabinet and has then been reduced to about 60% of its original weight. The temperature in the cabinet is about 25°C and the air velocity is about 2 m/s.

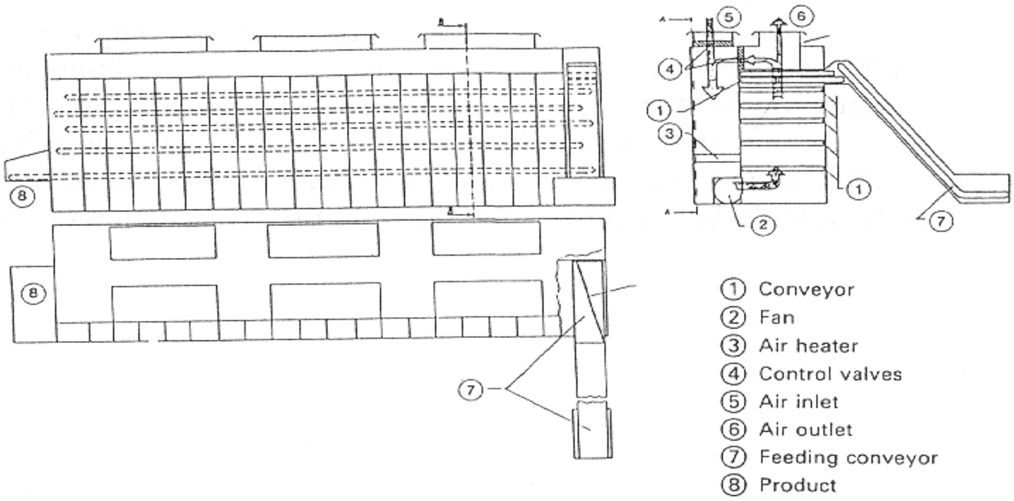

Figure 9: Continuous conveyor dryer for primary drying of cod-heads.

Secondary air-drying

When fish is dried in rack cabinets or in conveyor-belt cabinets, it is removed from the cabinet when the water content has reached about 50-55%. The fish is then placed in a drying container of l-2m^3 volume, (Arason, 2001). The container is located on top of an air tunnel duct and the air is blown up through it. It is possible to pile 3-4 containers on top of each other (see Figure 10).

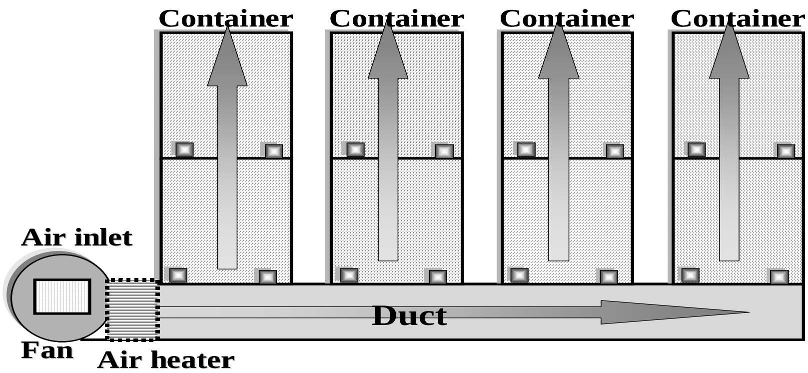

Figure 10: Secondary air drying unit.

7 Energy efficiency in indoor drying

Naturally, the energy efficiency in drying cabinets depends on many different factors. It is generally measured through energy use per each kilogram of evaporated water. The latent heat of water at 20°C is about 2,450 kJ/kg (585 kcal/kg), but in designing drying cabinets the figure 3,800 - 5,000 kJ/kg (900 - 1,200 kcal/kg) is most frequently used (Arason, 2001). The difference between these two numbers indicate a loss which can be divided into two types, conductivity and radiation losses on the one hand and thermal loss with the outlet air on the other. The drying cabinet being warmer than the surroundings causes the conductivity and radiation losses and the simplest way to reduce these losses, is to insulate the cabinet. They are, however, so small that it is generally not considered worth the while to do so. Heat loss through outlet air is dependent on the moisture content of the exhaust air. There are two ways by which the moisture content of the outlet air can be kept as high as possible: To make the cabinet very long or to recycle part of the air before it is let out. A very long cabinet has several disadvantages. It needs more space and the fish needs to be on movable carriages. Furthermore, there is more danger that the drying becomes more uneven and there is also the danger that the fish in the most humid air will dry so slowly that it will be spoiled. The use of energy of the blowers increases with added length of the drying cabinets, because of the increased resistance to the airflow. The length is therefore limited, because the use of electricity by the blower in most cases is more expensive than the heat that is used to warm the air. Therefore, it can be assumed that an increase in thermal efficiency of the drying cabinets through this method is an expensive alternative. It is, therefore, necessary to look at each individual case before action is taken, since it is difficult to come up with a general solution that is valid in all cases.

All the drying cabinets that have been constructed in Iceland have all been short, with automatic recycling of air. The thermal efficiency in these cabinets will never be as good as can be achieved in longer cabinets, but the initial cost is much lower because of simpler and smaller equipment. The thermal efficiency is greatly increased, compared with a cabinet where the air is blown through only once. In these automatically regulated cabinets, the energy use for evaporating the water is generally considered to be 3,800 - 5,000 kJ/kg (900-1,200 kcal/kg), compared with 5,400-6,600 kJ/kg (1,300-1,600 kcal/kg) before this technique was introduced.

One way to increase the energy efficiency in shorter cabinets could be to implement heat exchange in the air circulation. The heat exchanger would be utilized to pre-heat the inlet air, by cooling the outlet air and condensing the moisture at the same time. The main drawback of this would be the high expense of heat exchangers. Very large heat exchangers are required because of the small temperature difference between the cold and warm sides.

8 Conclusions

The use of geothermal energy for drying of fish and cod-heads is likely to increase in the future. The discussion is mainly focused on the use of geothermal energy in low-heat regions. The fishmeal industry is likely to use geothermal steam in the processing and hopefully within a few years, geothermal steam will be transported through pipes from Svartsengi to Grindavik, where many fish processing plants are located. It can be expected that the price of oil will increase more than the local energy in the future and therefore it is worth paying attention to the use of locally available energy sources for the fishing industry.

New, feasible alternative uses of geothermal energy are within sight, such as in freeze drying of food and one pilot project had analyzed that it is possible, it was recommended that a further work on optimizing the technique and a feasibility study for a freeze drying production be done (Gudlaugsson, 1998). Use of geothermal energy for drying is highly dependent on the price of crude oil and electricity and marketing prices of dried fish products. Equipment designed for drying fish can also be used for drying other industrial products.

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