SunCooler Development for the Potato Smallholders in Kenya

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Summary

Aim of this feasibility study is to make the SunCooler suitable for potato storage in Kenya. Upfront the perception is that that requires special focus on humidity management and energy consumption. Attention should be paid to both technique (equipment) and the way the technique is used (procedures).
The key aspects of potato storage are discussed. The optimal storage conditions in terms of temperature, relative humidity and CO_2 are listed and explained. Kenyan potato cultivars suitable for long(er) term storage are listed. To predict the required cooling capacity and the efficiency of solar panels climatological data are needed. These are listed. It is explained in depth why proper humidity management is important, but a humidifier is not necessary. In humidity management the focus should be on procedures: sorting of rots, dehydration of rots in the early stage of storage, and avoidance of condense. A number of aspects of energy efficiency are discussed, where the idea of just connecting a second hand reefer to a number of solar panels is challenged.
The report concludes with an experiment design for test pilots. It is recommended to first profoundly test the basic functioning of the system in The Netherlands, before it is shipped to Kenya for field tests to collect feedback from end-users.

1 Introduction

This research project has been carried out by Wageningen Food & Biobased Research commissioned and funded by Firmtec, in the context of SunCooler Development for the Potato Smallholders in Kenya. The research was carried out independently.
The SunCooler (https://SunCooler.com) is an invention of the Firmtec (www.firmtec.com) team.
It is a mobile cooling device that cools fruit, vegetables, meat fish, dairy and medicines on the spot in a cheap, sound and sustainable way. There is no need for fuel, a generator, a grid connection or batteries. The sun is the one and only source of energy. At the heart of the invention are a smart combination of PV solar panels and cheap second hand reefer containers.
In a running project the team, represented by Jan Hein Hoitsma, seeks to optimize the existing system for use in potato storage of small farmers in Kenya. Firmtec has asked WFBR to assist in a feasibility study. Aim of the feasibility study is to make the SunCooler suitable for potato storage in Kenya. Upfront the perception is that that requires special focus on humidity management and energy consumption. Attention should be paid to both technique (equipment) and the way the technique is used (procedures).

2 Potato storage

2.1 Optimal storage conditions

Standard works on the storage of potatoes are Rastovski and van Es (1987), and Bishop and Maunder (1980). For a readily accessible quick reference see Suslow and Voss (no year). The three climate parameters relevant to potato storage are temperature, relative humidity and CO_2. The following paragraphs address each of them separately:

1. Temperature. The optimal (long term!) cold storage temperature for maturely harvested (!) consumption potatoes is around 7°C. Seed potatoes are stored colder, at e.g. 2°C. Be careful when applying this guideline to the local situation in Kenya. The optimal temperature varies as a function of cultivar, maturity at harvest and possibly even storage purpose. Moreover it is common practice to first store potatoes for one or more weeks at warmer temperatures (± 15°C) for curing and drying, before reducing temperature to the optimal storage temperature.
2. Relative humidity. The optimal relative humidity is around 95%.
3. CO_2. As a rule of thumb potatoes in long term storage should not be exposed to more than approximately 0.4% CO_2 for prolonged periods (see e.g. Daniels-Lake (2013)). Higher CO_2 risks a brown frying colour during processing to chips or crisps. For potatoes that are not fried CO_2 is less relevant and excursions above this threshold probably have little effect, especially when these excursions are only temporary.

2.2 Current storage practice in Kenya

Mr. Hoitsma has inquired with http://npck.org/ about the current potato storage practice in Kenya and shared that information with WFBR in anonymous (2018). Anonymous (2018) refers to the NPCK_anonymous (2017), the potato variety catalogue issued by the National Potato Counsil of Kenya (NPCK). Table 1 summarizes the key parameters mentioned in that document.

Table 1, storage characteristics

variable	Description
Storage duration	Max. four months
Storage season	Any time of the year
Cultivars	70% is Shangi (see http://npck.org/catalogue/)
Regions	Esp. > 1500 m. above sea level
Current storage issues	Rots, weight loss, sprouting
Duration of tuber dormancy	< 1 month (for Shangi)
Sprout inhibitors	Legally not permitted
No. of store doors openings during storage	Very limited, in principle all sold at once.
Current packaging	Mostly bulk, sometimes bags or crates
Current storage method	Mostly stored in ambient temp. rooms
Other	The most grown cultivar is Shangi. Exactly that cultivar has a limited storage life.

2.3 Suitable potato cultivars in Kenya

Storage length is pre-determined by the cultivar characteristics, these should be known before high volume commercial storage commences. The cultivar of potato that is best suited for storage is one with long tuber dormancy period. This allows for delay in sprouting and hence retains better quality during and after storage.

The current and most planted potato variety in Kenya is ‘Shangi’. This variety is less suitable for storage since it has a very short dormancy period, meaning the tubers start to sprout within 2-3 weeks. Sprouted potatoes are less/not suitable for the fresh market and/or the processing industry. Cultivars on the NPCK variety catalogue (NPCK_anonymous, 2017) with long (≥ 2 months) tuber dormancy are: ANNET, ARNOVA, ASANTE, CAROLUS, CHULU, CONNECT, DUTCH ROBIJN, EL-MUNDO, EVORA, JELLY, KENYA BARAKA, KENYA KARIBU, KENYA MAVUNDO, KENYA MPYA, KENYA SIFA, KERR’S PINK, KONJO, KURODA, LADY AMARILLA, LAURA, LENANA, MARKIES, MAYAN GOLD, MILVA, NYOTA, PURPLE GOLD, RUMBA, RUDOLPH, SHEREKEA, TAURUS, TIGONI, UNICA, VOYAGER and WANJIKU.

3 Necessary climatological data

To predict the required cooling capacity and the efficiency of solar panels, following information is needed for the areas where the SunCooler is to be applied:

1. Minimum temperature (°C)
2. Maximum temperature (°C)
3. Relative humidity (%)
4. Typical diurnal pattern of solar radiation intensity (W/m2), and possible seasonal shifts in it.

In a quick google search https://en.climate-data.org/ was found. The site learns that seasonal temperature variations are very limited.
There is a pretty strong variation in rainfall, which might indicate a variation in solar radiation intensity.

Table 2, typical climatological parameters for some locations mentioned in (source: https://en.climate-data.org)

Location	Avg. min. temp. (°C)	Avg. max. temp. (°C)	RH (%)	Solar radiation
West Pokot provence (Nakinglas town)	14	28	To be done	To be done
Nakuru provence (Bahati town)	9	24	To be done	To be done

4 Temperature and relative humidity

4.1 The Mollier diagram explained

Figure 1 shows the Mollier diagram for humid air. It shows amongst others the relation between temperature [°C] (vertical axis), absolute humidity [g/kg] (horizontal axis), and relative humidity (the curved lines labelled with φ =…%).
In The Netherlands nearly every day the daily minimum temperature is close to the dew point temperature. Probably this is true for many other locations. Under that assumption the red dot in Figure 1 presents the usual air condition in West Pokot (Table 2) on the hottest moment of the day: 28°C and 7.5 (g water vapour)/(kg air). As Figure 1 shows the relative humidity then is 40%.
Cooling is first of all extracting heat, i.e. moving down along the large vertical blue arrow in Figure 1. Only when the temperature has been reduced to 9°C the air reaches 100% relative humidity. When cooling further there is a combined process of removing heat and moisture along the line of 100% RH: the small diagonal arrow in Figure 1, until the air condition reaches the (assumed) desired temperature of 7°C in the blue dot. Consequentially the relative humidity is high in the cooled air at 7°C. In a refrigeration machine with perfectly uniform temperatures on the evaporator coil the air condition at the evaporator air outlet is 100%. Practical evaporators have an average relative humidity of approx. 95% at the evaporator air outlet.

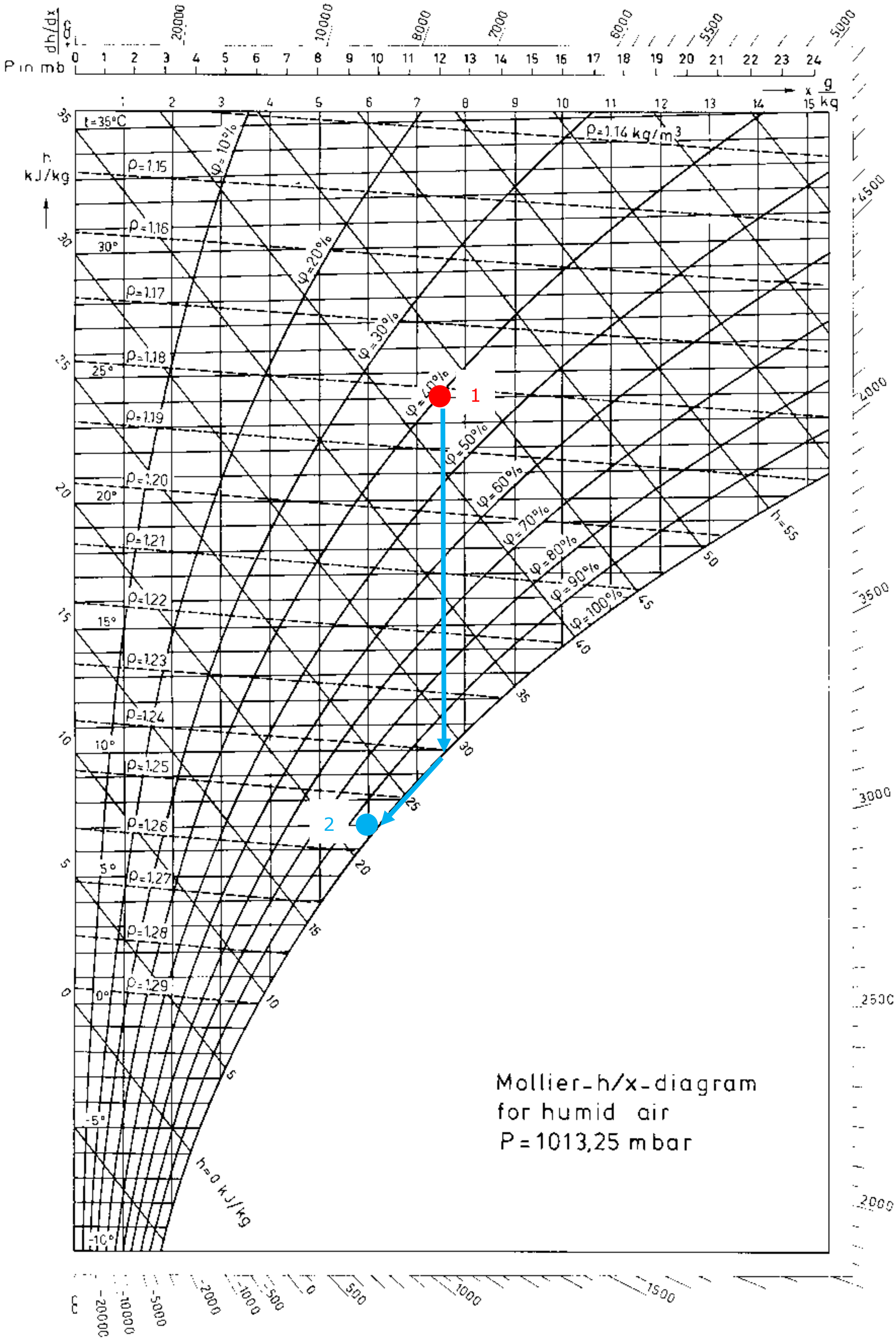

Figure 1, Mollier diagram for humid air

4.2 Humidity management in potato storage

From section 4.1 it is clear that in principle a humidifier is useless, or at least not something to start with, in a cold store. Yet humidity management is important in potato storage:

1. If after harvest there are rotten tubers in the store they need to be dehydrated asap to inactive them as a source of infection for the healthy tubers.
2. Avoid condense. Condense has the undesired potential to largely increase the growth potential for all sorts of microorganisms, esp. when also nutrients are freely available (wounds!). Therefore condense is to be avoided. Condense forms when warm/humid air hits a surface colder than the air's dew point temperature.
3. Weight loss is mentioned as one of the main problems in Table 1. Ways to reduce weight loss: reduce temperature, increase relative humidity, reduce air velocity at the tuber surface.

5 Energy efficiency

The SunCooler is not connected to the power grid. Hence the generated solar power should carefully match the electric power demand of the refrigeration unit. Moreover for financial reasons the installation of an excessive amount of solar panels should be avoided. Therefore energy-efficiency is important. Here some aspects are listed, without the intention to be complete:

1. In a standalone system the refrigeration unit should ideally use the electric power generated from the PV panels. This demands adjustment of the refrigeration unit's power uptake to the supplied PV power. By default a transport refrigeration unit is not designed for that way of operation. Hence an abundance of solar panels needs to be installed to warranty enough hours per day where the refrigeration unit can run. Without further measures it has to be accepted that the generated solar energy is not utilized to its full degree.
2. At night the sun does not shine, hence in principle the refrigeration unit does not run. What's the consequence in terms of:
    a. Nightly temperature rise in the container?
    b. Accumulation of CO_2 in the container?
    c. Condense formation in coldest spots in the container?
3. Would the costs and hassle of some sort of energy storage be justified by the issues raised above?
4. Fresh air exchange setting: limit the fresh air exchange setting to limit the ingress of warm humid air and the accompanying extra energy consumption and need for defrosts.
5. Defrost settings: don't defrost too often, but also avoid operating the system with a totally frosted evaporator coil.
6. Required electric power. The pulldown stage is decisive for this. In relation to that: the required rate of temperature pulldown after start of storage.
7. Energy efficiency and management of refrigeration unit (current limit, evap. fan speed, energy-savings software Quest, …). Carrier ThinLine is well-known for its robustness, but has a high electric energy consumption.
8. Working procedures:
    1. Remove the rotten potatoes from the harvested crop by sorting prior to start of storage in the container.
    2. Tubers left on the field after harvest assume a diurnal temperature cycle. Around sunrise they reach their coldest temperature. Load them into the room around sunrise to reduce the product temperature at the start of storage.
    3. Is a period of wound healing/drying needed at the start of the storage season?

6 Experiment design for test pilots

It is recommended to follow a structured test plan after a prototype has been assembled. Table 3 outlines the recommended steps.

Table 3, SunCooler prototype test plan

Phase	Description	Purpose	Duration
2	Set up the SunCooler and test the system in The Netherlands (in Wageningen?). After completion of this test just let the system run in the same location for a longer period of time.	Basic function test. To find and tackle first teething troubles before Duration test. Verify that the system can run trouble free for a prolonged period of time. Collect more data on the system performance	2 months e.g. 10 months
2A	After completion of phase 2, or possibly partly in parallel, run a true field test with a SunCooler in Kenya.	Collect feedback from the end-user to learn how they appreciate it, how it compares to the current local situation, and to learn which problems are encountered in the daily use in the end application	6 months

7 Analysis of feasibility project results

Aim of the feasibility study was to make the SunCooler suitable for potato storage in Kenya. Upfront the perception was that that required special focus on humidity management and energy consumption.
The results of the feasibility study are that it is clear that the installation of humidifiers is not needed, but humidity management is important. It seems most important to first focus on procedures: sorting, dehydration of rotten tubers in the early stage of storage, and avoidance of condense.
Upfront the message from Firmtec was that the choice to use second hand Carrier ThinLine units was a given, where its energy inefficiency would be compensated by an abundance of solar panels. Yet we challenge that choice. In terms of energy consumption this is not the best option. The Carrier ThinLine is robust, but energetically inefficient. Moreover the flexibility to adjust the electric energy demand of this unit to the energy supply from the PV panels is absent, or at best very limited.

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