Three hundred liters per day milk chiller
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Introduction

There is a need to transport milk from rural areas to the cities due to a shift of the populations. Warm milk will easily spoil during transportation and in particular milk collected in the evening has to be kept either until the morning or transported in the dark, which in most tropical countries is dangerous. There is thus a need to cool the milk before it is brought to the cities.

Requirements

Three hundred liters of milk needs to be cooled from 29 ^{o}C to 5 ^{o}C before the milk is shipped to a central processing facility. This requires a thermal cooling capacity of 30 MJ/d and the capacity to keep the cooled milk at 5 ^{o}C.

Diesel generators

Cooling of the milk using compressor refrigerators is the most likely option. For this electricity is required. Generating electricity with diesel generators is quite common in tropical countries. Diesel generators with a capacity of 4 kW_e consume about 0.5l/h idling. Fuel consumption increases from that to about 1.2 l/h at 3 kW_e..

The smallest power available for diesel generators is 2.5 kWe and operating at less than 50 % capacity will increase the specific fuel consumption drastically. It is therefore economic to produce electricity only for a fraction of the time. The capability to generate the start-up current of the freezer(s) has to be checked.

These small diesel generators run at 3 000 rpm. Fuel consumption can be reduced with a four pole generator and a speed of 1 500 rpm generating only 50 % of the nameplate capacity. A Sincro FK4 MBS 4 pole generator costs 1 100 €. Such a generator may be considered for the option with diesel fuel only.

Honda gasoline generators are about half the price of the 2.5 kW_e Hatz

diesel generator proposed, but their fuel consumption is higher and the capacity using biogas is significantly reduced compared to dual fuel diesel generators. The smallest Honda is 0.6 kW_e and uses 0.4 l/h of gasoline. The Honda EU20i with 1.6 kW_e uses 1 l/h gasoline. The gasoline generators are less durable than the diesel generators and have to be replaced within five years.

Sensible heat is stored in the form of brine or water/alcohol mixtures. The storage capacity can be enhanced using PET bottles filled with pure water. These will partially freeze. The most efficient way has to be tested experimentally.

Photovoltaic systems

The average daily insolation in Arusha (Tanzania) varies between 5 kWh/d in the rainy season and 6 kWh/d in other seasons. Sometimes there is no sunshine for a period of three days and generators have to supply the required power. It is no option to throw the milk away during those periods.

We assume on most days a solar yield of 6 kWh/kW_p. This is somewhat optimistic as solar panels never reach their W_p capacity.

The effect of clouds during freezing has to be accounted for. The freezers can be shut of and sequentially started after the cloud has passed. An electronic controller is required to perform the different operations.

The surge power of the compressors are a factor eight higher than the continuous power and the inverter has to cope with that. The surge power of the chosen inverter is 2400 W and is barely sufficient for the start up of a freezer 8*200 W. This requires a battery to deliverer the necessary energy.

Investments

In the following the investment costs for a number of options are compared. Prices are European. Chinese imports in tropical countries are generally only one third of the European.

Electricity is produced during six hours of the day.

There are a number of options

Table I Options

Cooling Method		Electricity generation	Fuel type	
Compressor cooling	230 V AC Single speed	Diesel generator	Diesel only	
			Diesel plus biogas	
		Photovoltaic	Solar inverter	With battery
				with 4 kWh battery
				With capacity bank
	Variable speed	Photovoltaic		
Absorption cooling		Thermal	Biogas	Water
				Ammonia
				Methanol
		Photo voltaic		Water
				Ammonia
				Methanol
				Zeolite
Peltier effect		Photo voltaic		

We have opted for an efficient standard freezer chest to make the comparison. Heat transfer to the water/brine in the freezer is better than heat transfer to air as in normal freezer setup and the costs for evaporators will be less. Tests should be made on the heat transfer of evaporator plates to brine

Freezers can also locally be constructed from parts. A 300 W_{th} Secop (formerly Danfoss) compressor with condenser cost 600 €. A 900 W_{th}

compressor condenser unit costs 900 €. These options requires a freezer chest and evaporators. Evaporators for 1 kw_{th} costs €2,500.

Table II Investment: compressor cooler, 240 V, diesel engine on diesel fuel

	Thermal capacity	Electric capacity	Required number	Investment
Compressor freezer Liebherr GTP 4656	Capacity 5 MJ/d	200 W	6	€5,000
Hatz generator				€1,900
Diesel fuel				€5,500
Total				€12,400

Diesel fuel at 0.7 l/h for six hours per day at a price of 0.7 €/l for five years.

Investment costs for biogas plants are size dependent. Different data are available:

- Fachagentur Nachwachsende Rohstoffe Germany $I = 33000\ P^{0.67}$
- Akut - Umwelt Kenya $I = 35\ 000\ P^{0.67}$
- Persistent India $I = 6\ 700\ P^{0.75}$

A 250 We biogas installation using the equation of the Fachagentur Nachwachsende Rohstoffe will cost € 13,000. The Persistent India formula gives a value of € 2,500. SNV promotes biogas installations for cooking that produce 1 m3/d of biogas with an energy of 20 MJ/d. The costs of a 8.5 m3/d biogas installation, using SNV technology is estimated at € 1,250. This does not include the equipment for H2S removal. H2S can be removed by injecting a small amount of air into the vessel and/or by adding some FeOH together with manure into the vessel.

We use the equation of the Fachagentur Nachwachsende Rohstoffe for a biogas installation.

Table III Investment: Compressor cooler, 240 V, diesel engine on biogas/ diesel fuel

	Thermal capacity	Electric capacity	Required number	Investment
Compressor freezer Liebherr GTP 4656	Capacity 5 MJ/d	200 W	6	€5,000
Hatz generator				€1,900
Biogas installation				€13,000
Diesel fuel (Dual fuel)				€1,300
Total				€21,300

Diesel fuel for 6 h/d at 0.1 l/h and a costs of 0.7 €/l for five years.

Dual fuel biogas/diesel engines are preferred. Modification can be done locally and the units can be serviced locally.

Batteries that can be cycled for 1800 times have been chosen, with a total capacity of 1 kWh. These batteries have to be replaced within a period of five years depending on the frequency of the passage of clouds.

Table IV Investment: Compressor cooler, 240 V, Photovoltaic, solar convertor and 1 kWh battery.

	Thermal capacity	Electric capacity	Required number	Investment
Compressor freezer Liebherr GTP 4656	Capacity 5 MJ/d	200 W	6	€5,000
Hatz generator				€1,900
PV installation		200 W_p	6	€1,900
Solar inverter Victron Phoenix		1200 W	1	€600
Batteries Eneloop		2.2 Wh	450	€800
Diesel fuel				€500
Total				10,700

Diesel fuel for 30 min/d on average at 0.7 l/h at a costs of 0.7€/l for five years.

Table V Investment: Compressor cooler, 240 V, Photovoltaic, solar convertor and 4 kWh battery.

	Thermal capacity	Electric capacity	Required number	Investment
Compressor freezer Liebherr GTP 4656	Capacity 5 MJ/d	200 W	2	€1,600
Hatz generator				€1,900
PV installation		200 W_p	6	€1,900
Solar inverter Victron Phoenix		1200 W	1	€600
Batteries Eneloop		2.2 Wh	1,800	€3,600
Diesel fuel				€500
Total				10,100

The batteries will last in this set-up for five years

A capacitor bank needs no replacement during a period of five years.

Table VI Investment: Compressor cooler, 240 V, Photovoltaic, solar convertor and capacitor bank.

	Thermal capacity	Electric capacity	Required number	Investment
Compressor freezer Liebherr GTP 4656	Capacity 5 MJ/d	200 W	6	€5,000
Hatz generator				€1,900
PV installation		200 W_p	6	€1,900
Solar inverter Victron Phoenix		1200 W	1	€600
Capacitor bank Boostcap		20 Wh	8	€2,000
Diesel fuel				€500
Total				11,900

Diesel fuel for 30 min/d on average at 0.7 l/h at a costs of 0.7€/l for five years.

Table VII Investment: Variable speed compressor cooler and Photovoltaic.

	Thermal capacity	Electric capacity	Required number	Investment
Compressor and condensor Secop BD220	450 W_{th}	320 W_e	3	€6,000
Hatz generator				€1,900
Meanwell 24 V power supply				€200
PV installation		200 W_p	5	€1,500
Diesel fuel				€500
Total				€10,100

Diesel fuel for 30 min/d on average at 0.7 l/h at a costs of 0.7€/l for five years.

A 24 V power supply is not necessary when a 24 V generator is used. A Stirling Power 24 V 140 A alternator costs € 500.

The SunDanzer DDR 165 solar refrigerator has a capacity of 165 l and can be directly connected to a solar panel of 120 W. It cools to a maximum of -1 ^oC. The price is 800 €.

Absorption coolers

Depending on the unit size, the capital cost of single-effect absorption chillers is roughly 20-50% higher compared to an equivalent electric or engine-driven chiller. The cost will be still higher for direct fired units and for double- and triple-effect units.

A Worldbank project using zeolite absorbent for a milk chiller is inactive and the Promethean project shifted from zeolite absorbent milk cooler to the transportation of thermal storage in India.

Peltier coolers

There are commercial Peltier coolers available, but those do not freeze and rely on permanent available electricity.

Table VIII Investment: Peltier cooler, Photovoltaic.

	Thermal capacity	Electric capacity	Required number	Investment
Tetech CP061	20 W_{th}	115 W_e	50	€12,000
Hatz generator				€1,900
Meanwell 24 V power supply				€240
PV installation		200 W_p	30	€9,000
Total				€23,000

The power density of Peltier coolers is more than 25 kW/m2 and the heat removal on the hot side is expensive and reduces the efficiency. The performance of Peltier coolers at low power densities is extremely poor.

Conclusions

Table IX Overview

Cooling Method		Electricity generation	Fuel type		Investment
Compressor cooling	230 V AC Single speed	Diesel generator	Diesel only		€12,400
			Diesel plus biogas		€21,300
		Photovoltaic	Solar inverter	With 1 kWh battery	€10,700
				With 4 kWh battery	€10,100
				With capacity bank	€11.900
	Variable speed	Photovoltaic			€10,100
Peltier effect		Photo voltaic			€23,000

The investment costs inclusive diesel fuel for five years are about €10,000 with the exception of the biogas and Peltier options. This is equivalent to about 0.02 €/l, which is attractive for farmers.

Considerations in order to decide between the options are the availability/ serviceability of the components in different countries. It seems likely that the electric generators will also be used for other (commercial) activities and this will influence the choice for a specific option.

Smaller distributed photovoltaic systems with gasoline engines can be used. Extra costs are due to the start-up currents of the freezers.

The thermal and electric capacities of commercial freezers need to be checked because the available data on these freezers are not consistent with the heat transfer data of plates to air. In the proposed scheme the heat transfer is from plate to brine. Ice forming on the plates reduces the heat transfer significantly. A lower heat transfer reduces the energy efficiency of the compressor coolers. Tests are required in order to compare the energy requirement of a scheme with ice as opposed to brine.

Attachement

I have found an extensive study from Denmark for milk chillers on solar energy (Katic et al. 2010). They prepared an example.

- To cool 150 l milk from 29 °C to 5 °C requires 5 kW_e/d.
- This energy can be produced by a PV installation with a peak power of 1.5 kWp and a yield of 5 kWh/d.
- They use a battery of 1 kWh.
- Capacity of the compressors is 2*250 W (Runtime 7 full power hours per day).
- Ice storage for 3 days with 15 kWh equivalent with 150 kg ice.
- cooling time of the milk 2 h.

Literatuur

Katic, I, Pedersen, P.H. and Jacobsen, E. 2010 “Standalone cool/freeze cluster driven by solar photovoltaic energy” Danish Technological Institute