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INTEGRITY, RELIABILITY & FAILURE IN REFRIGERATION SYSTEMS FOR DRAUGHT DRINKS

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ABSTRACT

A refrigeration system for draught drinks was monitored in order to evaluate its thermal performance using temperature, pressure and flow sensors. The first attempt to monitor the temperature of this machine was not successfully accomplished due to the failure of the thermistors used. All the system was repaired, and the sensors replaced by new ones with a special coating of epoxy to withstand the condensation around. Further tests were carried out with these new sensors, and integrity and reliability were achieved. The measured temperatures, pressure and flow rates of the refrigerant used in the refrigeration machine itself are in accordance with the simulations obtained based on thermodynamics analysis. In that way all the experiments carried out were validated. This paper presents the results of operation of the machine both in a simulation environment and in a real situation.

Keywords: refrigeration systems, draught drinks, simulation, measurements

INTRODUCTION

The refrigeration sector is nowadays one of the most important in our society. Its applications range from several medical usages (vaccine and medicine transportation, surgery, etc.), food preservation, leisure, human comfort, beverage production of almost all kinds, just to mention some of them. Among the applications there is one that it's also important: the refrigeration of draught drinks that can be found in almost the catering sector, such as bars, pubs, restaurants etc. The systems used to cool down draught drinks is usually based on simple vapor compression system that is mainly composed of four basic elements: compressor (hermetic type), expansion valve (capillary tube type), condenser (air-liquid) and evaporator (liquid-liquid) (Afonso, 2012). In this work such a refrigeration system will be study.

METODOLOGY

Usually the evaporator coil is immersed on a deposit containing water that freezes due to the heat removal from the evaporator coil. Inside the same deposit runs another coil coming from the beer barrel to the port where the beer is taken for drinking. In this way the beer is cooled down inside the deposit, as can be seen in Fig.1.

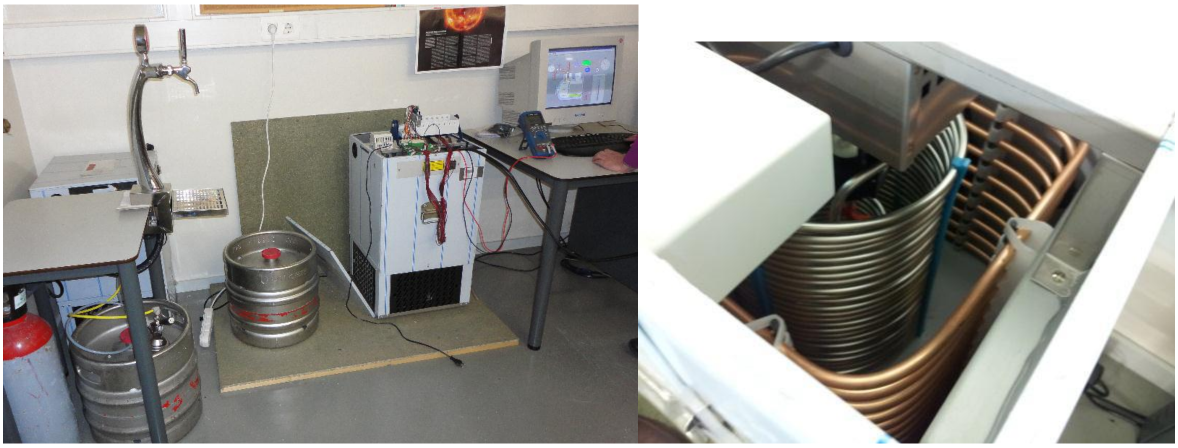

Fig. 1 Global system.

Monitoring temperatures in a draught beer machine is the first step to evaluate its behaviour and to develop new approaches for overall optimization. In the market, there are several types of temperature sensors that may be used for this purpose: Thermocouples, RTDs, Thermistors, and Pyrometers. Thermocouples allow a large temperature span (which is not the case) but require a more delicate reading circuit due to the low voltage output and cold junction compensation. Additionally, pyrometers are interesting for high temperatures or no contact applications, which is also not the case. On the other hand, a thermistor presents several advantages: it is rather small (2.4 mm diameter in our case), cheap, and very sensitive to temperature variation (around the ambient temperature). Though, since its response is exponential with the temperature, a computer system or a conditioner circuit must be used to implement the conversion characteristic (Faria, 2012).

Unfortunately the first 12 sensors placed over the circuit didn't stand for long. Water condensation, as well as the beer and vibration, eventually led to a failure of all thermistors. Then, a new type of sensors, reference 10K3A542I (from BETATHERM), were installed in the system in carefully chosen spots. These sensors are covered by a thermal conductive epoxy coating that makes them suitable for this harsh environment. As a conditioner circuit, two thermistors were placed in a wheatstone bridge which converts the resistance variation into a differential voltage that may be read by the data acquisition system. The locations of the sensors are shown in Fig.2 with the results obtained for a typical case.

Another source of problems of this machine, under long term operation, is the stirrer electric motor and respective bearings. Again, the condensation inside the motor seems to be the most probable cause.

The data acquisition system is based on a cDAQ system from National Instrument controlled by LabVIEW (LabVIEW, 2011). This solution enables a quick customization of a data logger system for all the signals, which includes temperature, flow (water and drink), pressure (before and after the compressor, as well as, before and after the expansion valve) and electric current (motor and control circuit).

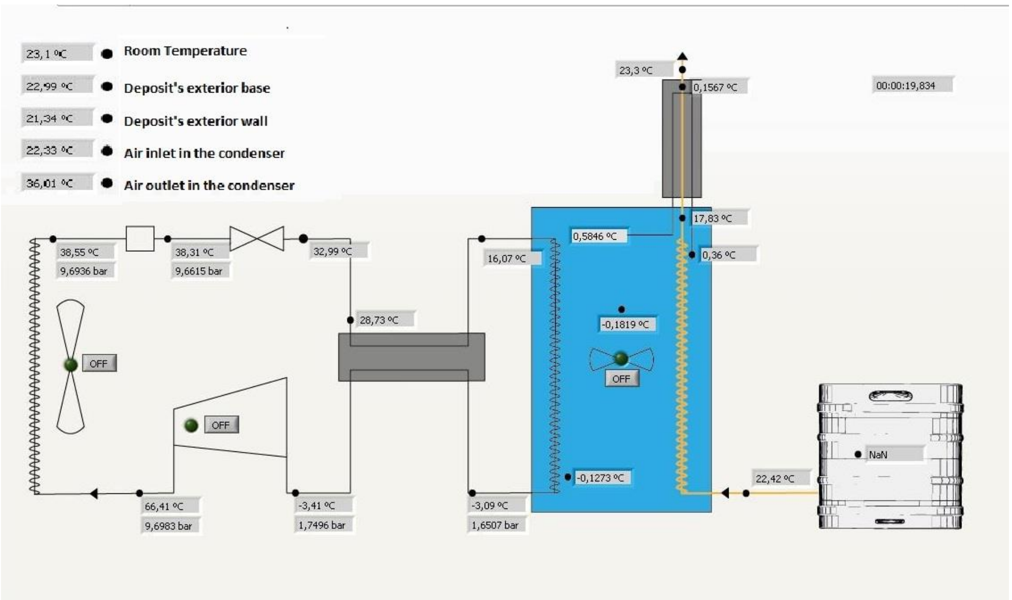

Fig. 2 Location of the sensors in the global system and the obtained results of a typical situation.

Simultaneously it was used the software Engineering Equation Solver (EES) to carry out several simulations as shown in the next sections.

For the simulations it was admitted that the beverage was beer, and the following data were considered as constant:

- The refrigeration system was already connected the day before the consumption and the ice mass in the tank was 18kg;
- The refrigeration system stops when the mass of ice formed is around 20kg;
- The beer temperature at the outlet of the column was 1ºC;
- The beer temperature in the barrel was equal to the average ambient temperature;
- The volume of the beer (density of 1050 kgm^{-3}) in each glass was 200 ml (0.21kg).

CASE STUDY 1 – RESTAURANT IN WINTER TIME

It was admitted that the beer barrel was inside the restaurant and the ambient air temperature inside varied between 15ºC at 00:00h and 20ºC at 15:00h (typical at Porto). The beer consumption was considered as shown in Table 1 (a common consumption).

Table 1 Beer consumption (glasses of 200 ml).

Time	Consumption
00:00 until 12:00	No consumption
12:00 until 14:00	20 glasses
14:00 until 19:00	5 glasses
19:00 until 24:00	10 glasses

In Fig.3 it is shown the beer consumption and the ice mass evolution along the time and Table 2 shows the results obtained with the simulations for this situation.

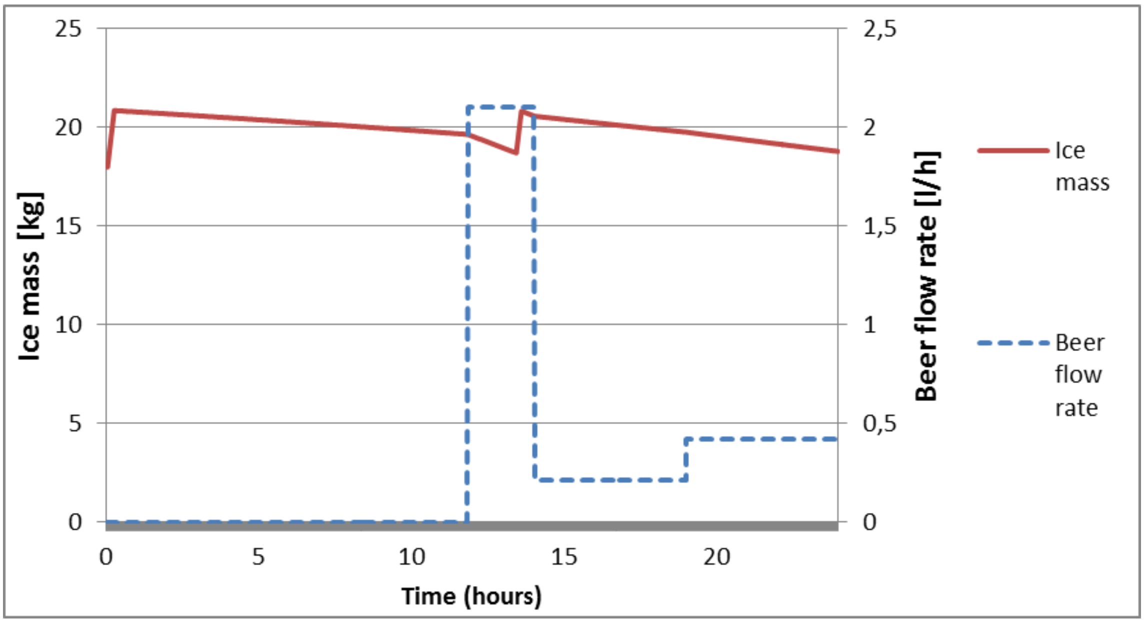

Fig. 3 Beer flow rate and ice mass evolution in the tank along the time.

Table 2 Results of simulations for case 1.

COP of the refrigeration system	Global COP	Working time of the compressor (min)	Energy spent by the compressor (Wh)	Energy spend by the fan of the condenser (Wh)	Energy spent by the stirrer (Wh)	Total energy consumption (Wh)
3.66	0.404	23	148.70	3.83	1320	1473

As can be seen there are two different ways to evaluate the COP. One is for the refrigeration system itself, i.e., the heat absorbed in the evaporator (to produce ice and overcome the heat losses through the walls of the tank) dived by the energy spent to overcome it, COP_R:

$$COP_R = Q_{evap}/W$$

Another one is to evaluate the COP of the whole system. Here the aim is to cool the beer from the ambient temperature to the one in the consumption tap, COP_G:

$$COP_G = Q_{beer}/W$$

In the first situation and as can be seen in table 1, the value of the COP_R is acceptable for this kind of refrigeration system, while the COP_G is very low. However, in this case, the desired refrigeration effect is obtained indirectly, namely first the evaporator produces ice water in which the beer coil is immersed. Thus, most of the energy absorbed by the evaporator is used to produce and maintain iced water, which is simply an intermediate process, and not the desired goal. In addition, there are also energy gains over the entire water tank envelope.

As can also be seen, the 20 kg of ice that the evaporator maintains in the tank (average) are not necessary. So, in this case, the formation of less ice should be sufficient for the same conditions. In that way, another simulation was run where the ice mass could vary between 8 and 10kg, the results being shown in Fig. 4 and Table 3.

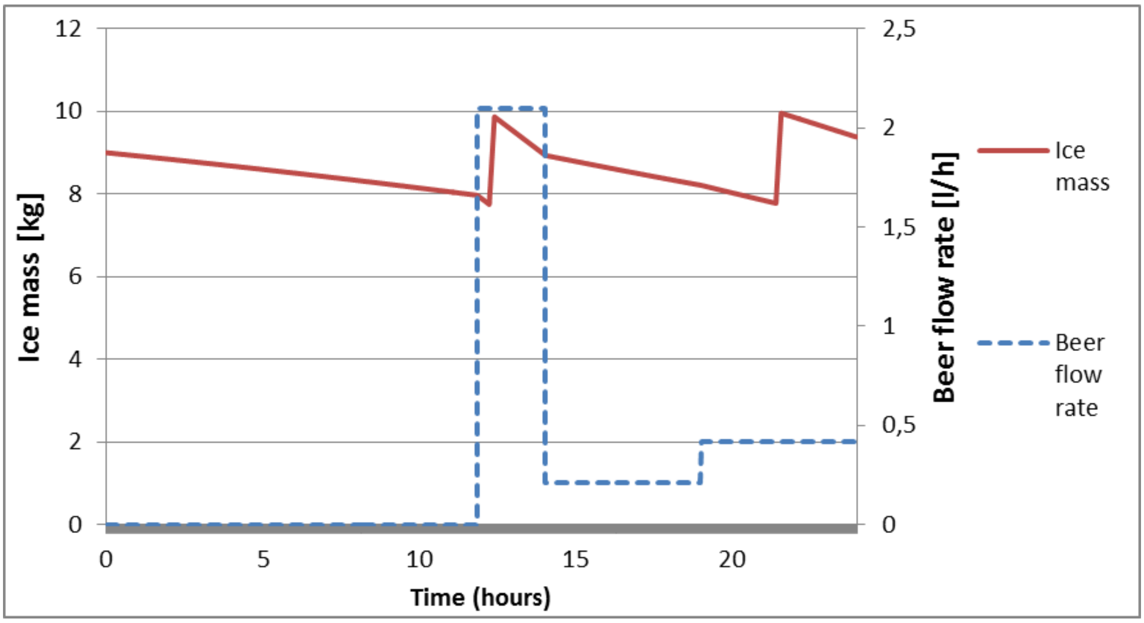

Fig. 4 Beer flow rate and ice mass evolution in the tank along the time (less ice).

Table 3 Results of simulations (less ice).

COP of the refrigeration system	Global COP	Working time of the compressor (min)	Energy spent by the compressor (Wh)	Energy spend by the fan of the condenser (Wh)	Energy spent by the stirrer (Wh)	Total energy consumption (Wh)
3.66	0.404	20	129.3	3.33	1320	1452

As can be seen from these results, the decrease of the total mass of ice in the tank did not affect the normal functioning of the global system as there was always ice inside the tank. Another advantage is that the total energy consumption decreased.

CASE STUDY 2 – RESTAURANT IN SUMMER TIME

It was considered the same restaurant of case 1, but working during summer.

The ambient air temperature inside varied between 18ºC at 00:00h and 23ºC at 15:00h. The beer consumption was considered the double of case 1 as shown in Table 4.

Table 4 Beer consumption (glasses of 200 ml).

Time	Consumption
00:00 until 12:00	No consumption
12:00 until 14:00	40 glasses
14:00 until 19:00	10 glasses
19:00 until 24:00	20 glasses

In Fig.5 it is shown the beer consumption and the ice mass evolution along the time and Table 5 shows the results obtained with the simulations for this situation.

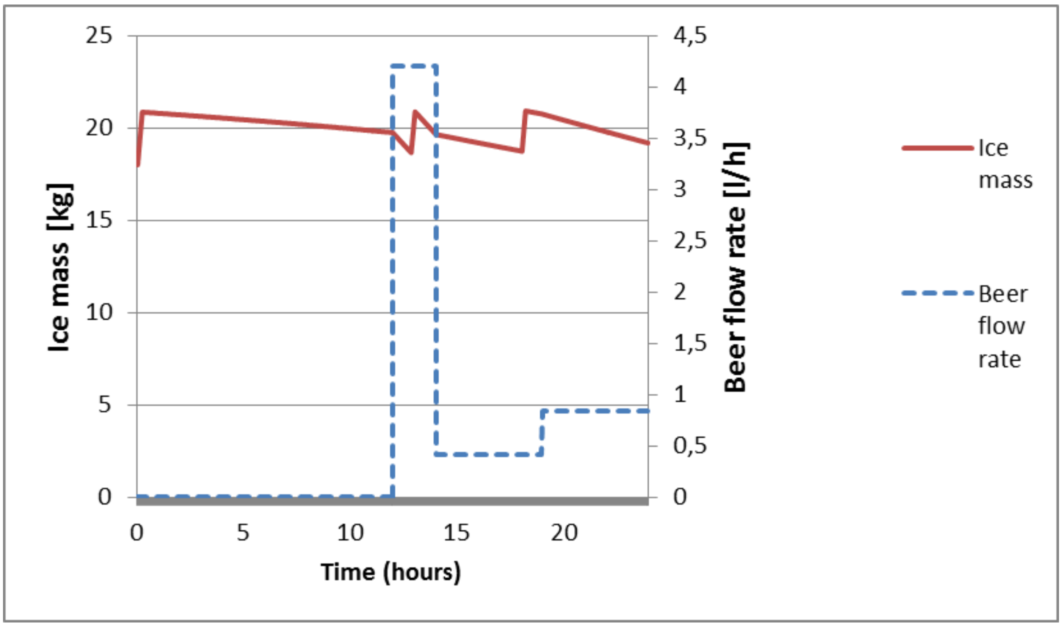

Fig. 5 Beer flow rate and ice mass evolution in the tank along the time.

Table 5 Results of simulations for case 2.

COP of the refrigeration system	Global COP	Working time of the compressor (min)	Energy spent by the compressor (Wh)	Energy spend by the fan of the condenser (Wh)	Energy spent by the stirrer (Wh)	Total energy consumption (Wh)
3.65	0.568	34	219,9	5.57	1320	1546

In spite of the beer consumption being the double of case 1 and the ambient air temperatures also being higher, it is possible to conclude that the system doesn't need all the ice produced. As evident the electrical energy consumed is also higher when compared with the first case.

So, similar to case 1, another simulation was carried out with less ice in order to see its impact on the performance of the system, as shown in Fig.6 and Table 6.

Again, the decrease of the total mass of ice in the tank did not affect the normal functioning of the global system as there was always ice inside the tank. Another advantage is that the total energy consumption decreased.

CASE STUDY – BAR IN SUMMER TIME

The ambient air temperature inside varied between 15ºC at 00:00h and 25ºC at 15:00h. It was chosen the summer time in the bar because there is more beer consumption, the pick period being between 22:00h and 02:00h, as can be seen in Table 7. The results from the simulations are shown in Fig.7 and Table 8.

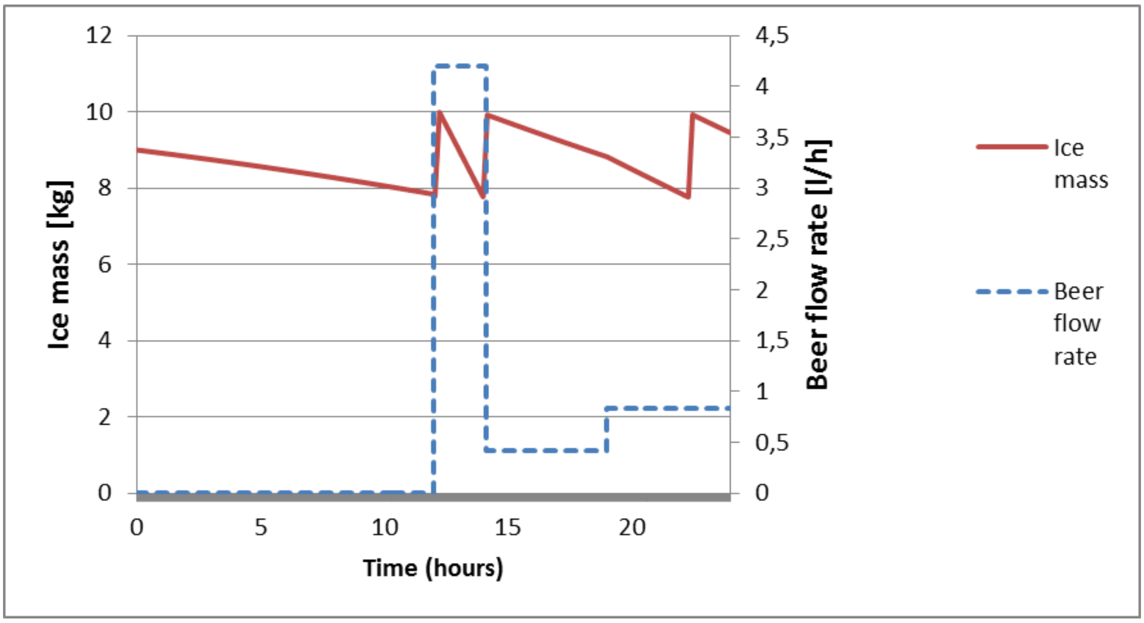

Fig. 6 Beer flow rate and ice mass evolution in the tank along the time (less ice).

Table 6 Results of simulations (less ice).

COP of the refrigeration system	Global COP	Working time of the compressor (min)	Energy spent by the compressor (Wh)	Energy spend by the fan of the condenser (Wh)	Energy spent by the stirrer (Wh))	Total energy consumption (Wh)
3.65	0.568	31	200.5	5.167	1320	1525.67

Table 7 Beer consumption (glasses of 200 ml).

Time	Consumption
10:00 until 14:00	No consumption
14:00 until 22:00	60 glasses
22:00 until 02:00	800 glasses
02:00 until 10:00	No consumption

As before it is possible to conclude that the system doesn't need all the ice produced. As evident the electrical energy consumed is also higher when compared with the other cases.

CONCLUSION

In this study a refrigeration system designed for cooling draught drinks was carried out in order to analyze the influence of the mass of the ice in the tank in the performance of the system. In all the cases studied it was possible to conclude that, in average, the refrigeration system could work perfectly with half of the mass of ice for which it was designed. This implies a decrease of energy consumed, with all positive consequences.

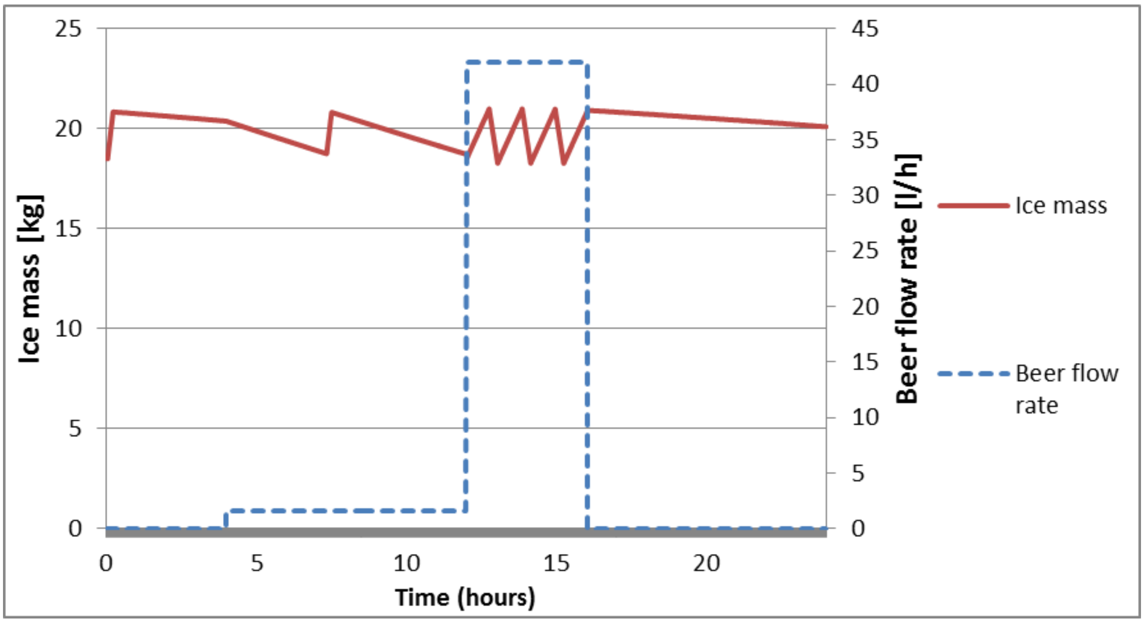

Fig. 7 Beer flow rate and ice mass evolution in the tank along the time.

Table 8 Results of simulations.

COP of the refrigeration system	Global COP	Working time of the compressor (min)	Energy spent by the compressor (Wh)	Energy spend by the fan of the condenser (Wh)	Energy spent by the stirrer (Wh)	Total energy consumption (Wh)
3.62	1.23	211	1364	35.17	1320	2720

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