THE PROCESS FOR REFRIGERANT SELECTION OF A MEAT PROCESSING PLANT, A GREEK CASE STUDY

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Our company in Greece has designed, manufactured and is currently installing the equipment for a meat processing plant in Larissa, Greece. The client company is currently in the 3rd expansion phase of the plant. We were required to provide and install the equipment for the expansion of the gyros production line as well as other production lines like skewered meat, burgers, steaks, fillets and more. The client's company started operations in 1995 with brand new refrigeration systems with R404A which was at the time cheap and a lot less complicated than ammonia. Since the first two expansions were always happening in small steps and funding was private with minimal help from banks, R404A was always the obvious choice for the first 22 years of operations. The study described here started in early 2017 when the first shortage of R404A was already a fact since the summer of 2016 and onwards.

Project details called for a bit more than 600kW of cooling capacity spread out among a variety of rooms. Table 1 shows the breakdown of the cooling capacity requirements.

Room type	Number of rooms	Total required refrigerating capacity kW
Static shock freezers	2	200,0
Spiral shock freezers	1	100,0
Storage LT -20ºC	3	25,0
Storage MT -2/0ºC	5	65,0
Air conditioned production rooms HT +10ºC	3	220,0

Table 1: Room refrigerating capacity requirements

The initial task at hand was to decide on a refrigerant that would cover the needs of the installation without compromising the reliability of the systems as well as being as future proof as possible. It was obvious that due to the FGas regulation 517/2014, R404A would not remain an option for long and any new systems with R404A although still legal would have servicing problems in the near future. The refrigerants that were already tested by the market and were reliable enough to go into were R407F, R449A, R717 and R744/R134A cascade. One condition that was initially set by the client's management was the use of a single refrigerant for all new systems that would be installed. An exception was made specifically for R744/R134A cascade [1] since it was

[1] Although R744/R134A cascade means completely different things according to EUR517/2014, here the term means the traditional cascade system were R134a condenses CO_2 while at the same time it is evaporated in coolers for the medium and high temperature rooms.

extremely promising and there was no flammability involved for the combination.
It was clear that the required capacities were well inside the ammonia comfort zone so it would definitely be a serious candidate. CO_2 was also on the rise at the time with cascade systems and was a logical choice for investigation. If the customer elected to go with the more traditional refrigerants, then the closer replacements to R404A, the blends R407F or R449A would be used. Table 2 shows some of these refrigerant properties which play a significant role depending on the application and the refrigerated product.

	R404A	**R407F**	**R449A**	**R717 (ammonia)**	**R744 (CO_2) /R134A cascade**
GWP (IPCC AR4) [2]	3922	1825	1397	0	1 / 1430
EN378 classification	A1	A1	A1	B2L	A1 / A1
Temperature glide K	0,7	6,4	4,5	0	0 / 0

Table 2: Some basic properties of refrigerants under consideration

Other factors than the usual properties of refrigerants would also be looked into. There are a lot that matter depending on the kind of system investigated but some stand out more than others. In no particular order these were:

1) Familiarity. Every refrigeration system user prefers to continue with the refrigerant he has already learned how to use. It is not easy to change, with good reason, as the safety of the systems always calls for a degree of familiarity to avoid break downs or accidents.
2) Investment costs. Initial costs are the driving factor of each new investment. There is no point in discussing alternative solutions if the costs are forbidding to the end-user.
3) Running costs. They are also a driving factor for the serious investor. There is no point in investing in low starting costs and losing money for the next 15-25 years wasting energy on cheap but energy intensive systems. A balance between investment and running costs had to be found.
4) Direct environmental impact. EUR517/2014 had to be followed. Refrigerants with GWP of more than 2500 would be soon phased out and so a more environmental solution was called for. Since the plant was a non-commercial installation, most of the restrictions for new installations were not going to be a problem. One way was to go full "green" and select an ultra low GWP like ammonia or CO_2 cascade. The other way was to use a refrigerant like R407F or R449A with a higher GWP but an expected life in the market of around 5-7 years and then to change to a newer refrigerant with similar properties but of lower GWP when the need arose. Direct emissions should be kept to a minimum not only by designing a safe

[2] Although AR5 exists, AR4 must be used instead as the FGas regulation and all restrictions and phase downs are based on that.

system or by using a low GWP refrigerant, but also by fast reactions and minimal loss if it ever came to having an actual leak. There would be a plan to manage the emissions no matter the GWP of the refrigerant.

5) Indirect environmental impact. There is no sense in designing new systems with less direct emissions if the indirect ones increase disproportionally by increased electricity consumption. TEWI although not included in EUR517/2014, in our opinion should be at least considered in every new design.
6) National and local legislation. Most countries have some kind of laws that allow or disallow certain fluids/gases to be used in certain areas like industrial areas, residential areas, areas of outstanding natural beauty and more. A lot of times the use of certain fluids is outright banned, in certain cases and so close attention to these laws had to be paid. Flammability, toxicity, maximum refrigerant charges, land usage and more were things to be thoroughly investigated.
7) Condensation and ambient conditions. There is no sense in adopting a system that is operating inefficiently or close to its limits because the ambient conditions are against it. An example would be transcritical CO_2 in very hot climates without the use of very specific design features like ejectors that rose up in the market later on. Not only are ambient conditions important but the type of condensation also. There are always areas in Greece with reduced availability of water for cooling towers or hard underground waters that cost too much to treat and so these should be checked for from the beginning.

With all these in mind we started an assessment, the next step of the process, for the possibility to use each refrigerant and any obstacles that might prevent their use. Since ammonia was the biggest candidate we started looking into the construction permits of the building, the surrounding area that the plant was located in, national and local building codes, national and local fire department codes and other relevant data that could restrict the use of the systems under consideration, the following major points were formed:

1) The area that the plant was situated in was not an industrial area and although there were no restrictions due to residential areas up close, it was situated inside the Tirnavos NATURA 2000 marked area. There was no restriction on the current processes already undertaken in the plant but the usage of toxic ammonia would become a problem as the NATURA area was a bird sanctum. According to the Greek building codes, ammonia is generally free to be used in industrial areas and some other non-residential areas well outside cities or villages but there is always a restriction on the amount to be used unless there is a round the clock shift engineer overseeing the installation. That was a restriction that would definitely increase the running costs of the already expensive ammonia.
2) The plant area is situated between two rivers in the Larisa valley. Although far enough (8 and 15km) to not be able to use the water directly from the rivers, the underground water tables would in theory cover all of the needs for evaporative towers. Unfortunately there was an active restriction on the area for underground

water extraction, due to past draughts, giving priority to the agricultural sector of the valley. There would be not enough water coming from an underground bed to cover our needs for evaporative cooling towers. .

All of the points that were formed from the area restrictions meant that ammonia would become even more costly than normal and its use was looking more and more remote. With that it was high time then that we checked the possibilities of using CO_2 cascade. CO_2 is very close to the traditional refrigerants with the exceptions of the high pressures that must be accounted for all over the design. R134a could be used for the medium and high temp rooms and if it ever came to having problems with sourcing this refrigerant due to the gradual phase downs of GWP, we could always retrofit with R513A with no costs besides the refrigerant costs. Immediately the preliminary design of the thermodynamic cycles started and the first doubts came to be. It was clear that R744A/R134A cascade had very similar COP with the traditional refrigerants under investigation but the investment costs would be higher. Not only components were more expensive at the time, coolers and pressure vessels mainly, but cascade meant that you needed more or less double the number of compressors to do the same job that HFCs did which also meant almost double the machinery room space, a luxury that could not be easily afforded on the plant.

The remaining two refrigerants to be inspected were R407F and R449A. These are quite similar in properties but as it seems, R407F tends to give higher discharge temperatures which in reciprocating compressors means liquid injection cooling and reduced COP. Fortunately the size of our plant meant that screw compressors with economisers would be more suitable and thus we would avoid the COP loss. The two main disadvantages of these refrigerants would surely be the increased GWP in comparison to the natural ones and the large temperature glide due to them being zeotropic mixtures. The impact of the zeotropic blends always affects the heat exchangers of the system; mainly the condenser which requires larger surfaces for the same condensation power or it will result in higher condensing pressures and temperatures. While DX air-coolers usually benefit from such a glide as the DT of the evaporation increases, meaning low and very low temperature coolers would also benefit, it also meant that our medium temperature coolers would dehumidify the products as big DTs tend to remove humidity from the environment. Fortunately the capacity required by the medium temperature coolers was not big and the problem could be avoided by enlarging their surface. Thus an increase in costs compared to R404A was unavoidable even with the very similar R407F and R449A.

A direct comparison of the COPs was drawn at two operation points that were deemed fair, one at +35 condensing temperature for cooling tower use and one at +45 for use with air-cooled condensers. The HFCs and ammonia were calculated with open type screw compressors and CO_2 with semi-hermetic reciprocating compressors for the low side and open type screws for the high side. All screws were operating with economisers. Table 3 shows the COP comparisons against R404A at these two points.

	R404A	**R407F**	**R449A**	**R717 (ammonia)**	**R744 (CO_2) /R134A cascade**
COP of compressor pack operating at -38/+45	1,02	0,98	1,01	N/A	1,11
COP of compressor pack operating at -38/+35	1,41	1,40	1,36	1,42	1,38

Table 3: COP comparison (SH=10K and SH=5K for NH3, subcooling from economisers only)

It was clear that the COPs were for the most part similar and the prime drive for the selection of the refrigerant was going to be what usually comes to be at the end, costs and familiarity. The customer made up his mind and selected R407F or R449A, whichever we thought had the best future because of his familiarity with R404A and of the cheaper investment costs. He would also not risk the use of evaporative towers and having his production halted in case of stricter water usage rules and so the nominal condensing conditions were fixed at 45ºC with air-cooled condensers. From our side it was finally an easy choice to go with R449A as the lower GWP made it the safer choice for the immediate future. Table 4 shows advantages and disadvantages of the compared refrigerants for the plant's new systems.

	R407F	R449A	R717	R744/R134A cascade
Familiarity	++	++	- -	-
Investment costs	++	++	- -	-
Running costs	+	+	-	+
Direct environmental impact	+	+	++	++
Indirect environmental impact	+	+	+	+
Future proof against EUR517/2014	-	-	++	-
Legislation (National and local)	++	++	- -	++
Condensation and ambient conditions	++	++	- -	++

Table 4: Comparison table of refrigerants under consideration against existing R404A

Having selected the refrigerant did not mean that the job was completely done. There was one more thing to do in order to meet the goals we had set. That was to ensure that there would be minimal emissions both direct and indirect for that specific refrigerant, since this is the main drive behind the EUR517/2014. That meant further optimisation of the plant systems on energy efficiency and leakage minimisation. It was decided that energy saving technologies that are useful on all refrigerants would be used. Frequency inverters, soft-starters, electronic expansion valves, heat recovery for hot water, adiabatic air-cooled condensers, EC fans, floating condensation algorithms would all be technologies and techniques that would be applied in our systems in order to maximise the energy saving and hence the indirect emissions from the plant.

Finally, the aim for complete leak detection coverage was set both for the new and the old systems with any leakage occurring being quickly detected. In case of a major refrigerant loss the solution would come from the ammonia systems safety controls. We decided to separate the refrigerant system in different compartments that could be isolated by solenoid valves in case of high level leakage detection. There would be two solenoid valves, normally closed, one before the liquid receiver and one after it to isolate the majority of the refrigerant and keep it safe, while the compressor operation would be halted. Four major compartments were then created to isolate the refrigerant, one for the discharge line and liquid line before the receiver, one for the liquid receiver, one for the liquid line up the expansion valves and one for the suction line. A separate safety valve on the discharge line would provide relief in case of leakage and simultaneous pressure increase in the discharge line, while a third safety valve on the liquid line would relieve the pressure after the receiver if for some reason the pressure in that compartment arose with a halted system. In this way there could never be a total refrigerant loss outside of a liquid receiver rupture.

With all choices for refrigerants finalised and leakage safeties designed for, the process for selection was complete.

References:

1) Intergovernmental Panel on Climate Change (IPCC) 4th assessment report, 2007
2) European FGAS regulation 517/2014
3) European standard EN378:2016 parts 1 to 4
4) Greek fire protection code on industrial buildings
5) Greek legislation and requirements on land use
6) Bitzer software (www.bitzer.de)
7) European Environment Agency, Natura 2000 network viewer (natura2000.eea.europa.eu)
8) Bitzer refrigerant report 20, A-501-20