

A.C.E.
Final Report

**AIR CONDITIONING USING STAINLESS STEEL PIPE
& CLEAN EXCHANGER FOR FOOD PRODUCTS**

ACE

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TMI

Contract JOE3-CT98-7028

1. PUBLISHABLE FINAL REPORT

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2. TABLE OF CONTENTS

<u>1.</u>	<u><i>PUBLISHABLE FINAL REPORT</i></u>	<i>1</i>
<u>2.</u>	<u><i>TABLE OF CONTENTS</i></u>	<i>2</i>
<u>3.</u>	<u><i>ABSTRACT</i></u>	<i>3</i>
<u>4.</u>	<u><i>PARTNERSHIP</i></u>	<i>4</i>
<u>5.</u>	<u><i>TECHNICAL DESCRIPTION OF THE PROJECT</i></u>	<i>6</i>
<u>5.1.</u>	<u><i>General</i></u>	<i>6</i>
<u>5.2.</u>	<u><i>Hygiene</i></u>	<i>8</i>
<u>5.3.</u>	<u><i>Thermic</i></u>	<i>9</i>
<u>5.4.</u>	<u><i>Hygrometry</i></u>	<i>11</i>
<u>5.5.</u>	<u><i>Thermic, Hygrometry & Aeraulic Trials</i></u>	<i>12</i>
<u>5.6.</u>	<u><i>Companies Trials</i></u>	<i>13</i>
<u>6.</u>	<u><i>RESULTS & CONCLUSION</i></u>	<i>16</i>
<u>7.</u>	<u><i>EXPLOITATION PLAN & ANTICIPATED BENEFITS</i></u>	<i>17</i>
<u>8.</u>	<u><i>PICTURES</i></u>	<i>18</i>

3. ABSTRACT

The aim of this project was to develop a new atmospheric air conditioning system using smooth-tube, horizontal **thermal exchangers for the food industry**. The central thrust of the project was to find suitable thermal exchangers and validate the **hygiene performance** of this atmospheric air conditioning system. Additional aspects such as the problems of industrialisation (flexibility and safety) and cost will be addressed, along with an underlying concern to reduce **the impact on environment**. The whole process will be validated by tests carried out in laboratories and food factories.

Regarding thermal research, the results we reached in terms of mathematical and numeric modelling make for possible results with superior performances to the initially supposed ones. This is very promising for the future industrial development as it was one major limitation factor pointed out by MONDIAL FRIGO when they built their first machines. Heat exchangers are designed following mathematical models and their functioning, optimised according to a whole set of criteria influencing heat transfers. The second step was to validate and correct numeric models in accordance with the results of the industrial trials and to design the software regarding the performance of the exchanger as foreseen in the project. The results prove that the numeric model with small amendments (between 5 to 15% depending on temperature, hygrometry or air velocity) is validated. A software was created in order to do accurate sizing for end users (agro-food plants) needs.

The other research tasks were based upon the hygienic conception of the exchanger integrated into an air conditioning box thoroughly cleanable as well. A complete pilot prototype has been built in order to do all necessary tests to validate Thermal, Hygrometric, Hygienic, & food products requirements. The cleaning tests have been done not only on the exchanger but on the whole equipment itself and the results prove that it is easily cleanable and it satisfies hygiene recommendations (EHEDG).

In terms of hygrometry, temperature homogeneity, test was done with the complete machine and demonstrate that with some adaptation, regulation & optimisation, we can reach the foreseen target (More than 95% Hr and we were around 93%)

In fine, after plate form trials & optimisation, tests done with food products in factories and losses were reduced respecting food products safety & quality (better quality on cheese crusts for example). In this case, with regulation optimisation, the high hygrometry, > 95 Hr, was obtained continuously.

Dissemination on this project has been done at the **Food Safety Europe conference in London** and at **IPA Paris** (food equipment exhibition, on the 3 major exhibitions in Europe). A CDROM and a poster were been done for these events.

Now, this project is finished and the product is in course for industrialisation and commercialisation. Despite this project just finished, the contractor is about to sell some complete air conditioners, based on ACE technology, in a dairy which invests more than 1 Million € for air conditioning.

4. PARTNERSHIP

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OBJECTIVES OF THE PROJECT

- **AS FORESEEN FROM THE DESIGNING OF THE PROJECT :**

The aim of this project is to develop a new atmospheric air conditioning system using smooth-tube, horizontal thermal exchangers for the food industry. The central thrust of the project is to find suitable thermal exchangers and validate the hygiene performance of this atmospheric air conditioning system. Additional aspects such as the problems of industrialisation (flexibility and safety) and cost will be addressed, along with an underlying concern to reduce the impact on the environment. The whole process will be validated by tests carried out in laboratories and food factories. The final phase will look into the feasibility of creating a recommendation or even a norm for the EHEDG which would be specific to atmospheric air conditioning equipment.

The research approach adopted will be broken down into problem-solving sequences:

- Validation of the **design from a hygiene point of view** (forms, overlap of exchanger tubes, positioning of cleaning equipment, materials used) and the ease with which it can be cleaned.
- Search for understanding and modelling of thermal and climatic exchanges (as a function of hygienic design, quest for optimum performances, parameters for size and operating principles, optimisation of exchanges, materials to be used) for air conditioning in premises used for food. We shall therefore be concentrating on establishing a computerised reference model allowing us to take into account all the parameters affecting these exchanges (whilst respecting hygiene regulations). This model will allow us to identify the size of exchanger needing to be installed. Also, we will be looking to pin down the limitations of this technology so as to optimise exchanges and work at very high levels of hygrometry (> 95% Hr).
- Cost study and validation: on the basis of the completion of a prototype and industrial-scale tests, we will analyse the costs that would be incurred in adopting this technology and the financial advantages it might hold for the end user.

- **FULLY CARRIED OUT DURING THE 2 YEARS**

- **OBJECTIVES REACHED!**

5. TECHNICAL DESCRIPTION OF THE PROJECT

5.1. GENERAL

5.1.1. Product Specifications

5.1.1.1. Products (and/or)

- (microbiologically) sensitive products
- products with a high water content, maintaining high humidity / water activity, limitation of weight loss

- ⇒ Cheese of the cooked and pressed type with "*morgée*" crust (substantial a_w on surface)
- ⇒ Soft cheese
- ⇒ Blue type cheese
- ⇒ Minced meat
- ⇒ Freshly-cut produce (or ready-to-use raw vegetables)

Temperature : 2 to 20°C
Hygrometry : 70 to 98% Hr
Air speed : personnel comfort (residual) 0,2 m/s
Weak on products

No air contamination

Specificity of premises: homogeneous in temperature and in hygrometry

The trials on the housing designed will be carried out on products of the above types.

5.1.1.2. Specifications / materials

Reminder from the application:

We are trying to construct an air-conditioning device with a steel tube exchanger in a horizontal position which is easily cleaned, able to operate at high levels of hygrometry, with known, identified and optimised performances. This equipment will be targeted toward agro-food industries (sensitive products and/or those with a high water content) and usable in pharmacy. There are some specifications for:

- | | | |
|-----------------------------|-----------------------------|-------------------|
| 1) Location | 2) Norms | 3) Exchangers |
| 4) Fluids as energy support | 5) Ventilators - Fans | 6) Humidification |
| 7) Condensates | 8) Chamber | 9) Hygiene |
| 10) Cleaning equipment | 11) Regulation of equipment | 12) Environment |
| 13) Materials | 14) Control points | 15) Sensors |

A.C.E.
Final Report

5.1.2. Specification and drawings for the prototype

The specification and prototype design were completed ahead of schedule. Nevertheless, they have been completed and the prototype is constructed according to these findings.

5.1.3. Regulation

A regulation survey has been done in order to choose the regulation system (All or nothing, Fully Modulate).

During plate-form & plant trials, a regulation program has been adopted in order to use all the possibilities given by the system and also to use sensor information (Temperature, Humidity, Air speed) in the best condition,

5.1.4. Prototype Construction

A prototype was built in order to do all the necessary trials (thermal model, hygiene conception, hygrometry functioning & effects on food products).
(see Picture at the end)

5.2. HYGIENE

Following a visit to Mondial Frigo in Lyon on 14/12/98 to discuss the role of the Participants and view an existing design of heat exchanger under construction, first prototype, an initial meeting of the UK Partners (JPS and Wyattair) was held at CCFRA on 15/2/99 to discuss ideas for a cleanable heat exchanger system. The structure of the Project was finalised at the 'Kick off' meeting held with the Commission representative in Brussels on 26/2/99.

The first design meeting was held at CCFRA, attended by JPS, Wyattair, TMI & ATEM on 19/3/99. The main issues discussed were:

- Optimisation of tube spacing and configuration to maximise heat transfer, which ATEM would model using Computational Fluid Dynamics (CFD).
- Avoidance of shadowing between the tubes which would impede cleaning.
- The positioning of fans for distribution of conditioned air
- Initial housing designs incorporating a traversing clean in-place (CIP) system.
- Materials for construction and surface roughness values based on the requirements of the relevant document search conducted by CCFRA (see (1) above).

During the modelling process conducted by ATEM on tube configurations and heat transfer characteristics, CCFRA and JPS developed a design for an external manifold system for cooling medium supply which would eliminate return bends on the tube banks within the exchanger housing. Tube and plate weld samples were prepared by JPS, using both orbital TIG welding and Plasma welding systems, and sent to CCFRA for inspection. The quality of welds produced using the Plasma welding system were of extremely high quality and, therefore, this technique was chosen as the preferred method where access for the machine was not restricted. High quality TIG welding would be employed for the remaining areas.

The next phase of the design process involved selecting suitable cleaning and humidification systems to be situated within the exchanger housing. The humidification nozzles & cleaning systems were chosen after trials

During these selections, a drawing scheme of the equipment was done and a complete air conditioner built

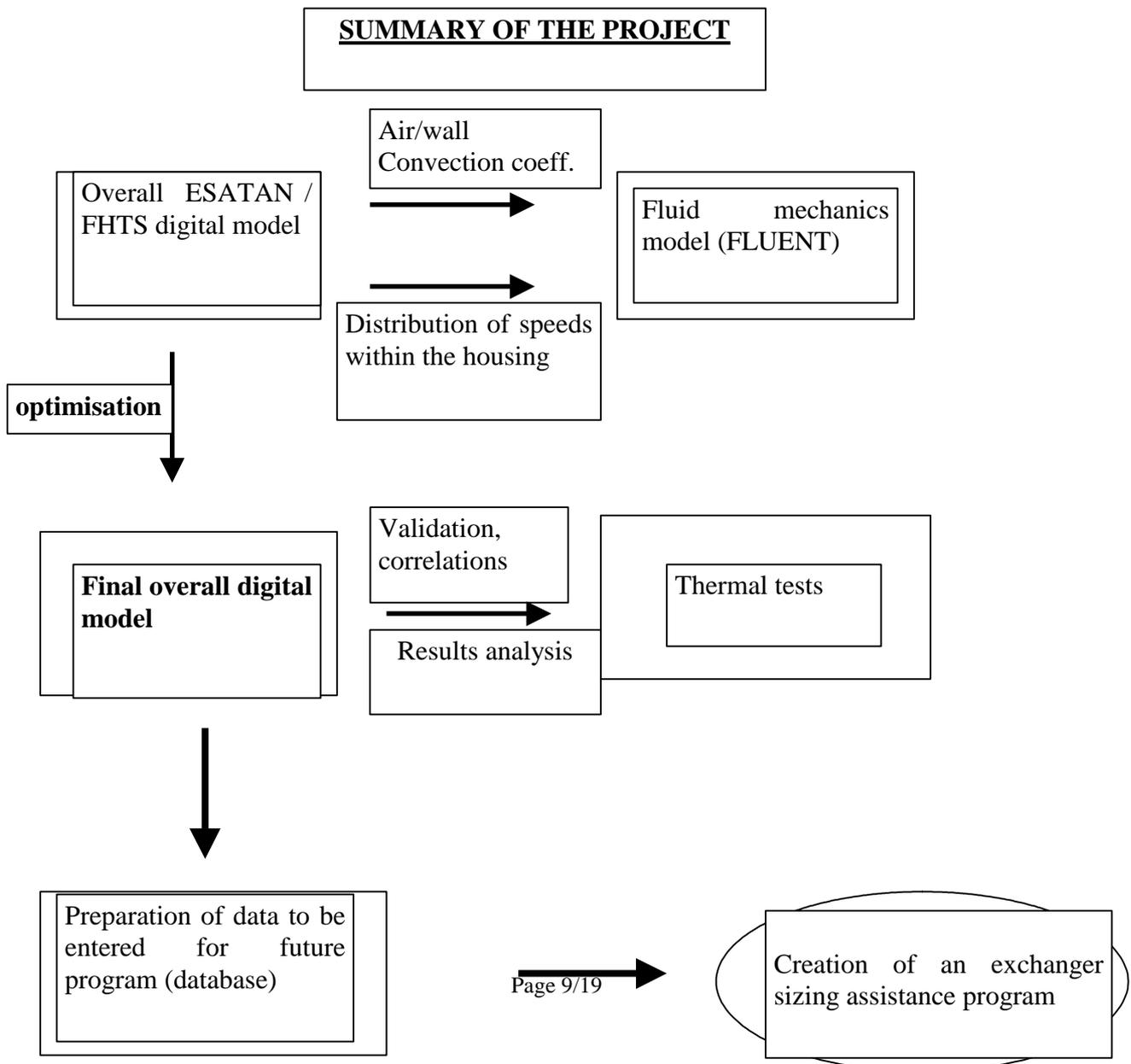
After that, all the air conditioner was tested in order to know its hygiene performances.

In conclusion, as a result of the design recommendations given and the cleaning trials conducted on the internal surfaces of the prototype heat exchanger unit it has been clearly demonstrated that all objectives set within the Contract JOE3-CT98-7028 for CCFRA have been successfully achieved. The equipment is fully & easily cleanable.

5.3. THERMIC

The European project involves the study and construction of an air conditioning unit housing equipped with a bank of smooth horizontal tubes mounted in staggered rows. On account of difficulties concerning the specific characteristics of the material under design (thermal and ease-of-cleaning considerations), the need was identified to design software to assist with the sizing of the exchangers. In this area, the work perform can be detailed in the following terms:

1. assistance in the choice of design for the exchanger
2. optimisation of the architecture of the exchanger: the tool used for this optimisation process is a digital model which takes all the major parameters into consideration
3. a detailed study of the final exchanger design
4. definition of the architecture of the exchanger sizing assistance software
5. thermal experiments on the exchanger
6. exploitation of results, validation and correlation of the mathematical model and preparation of specific entry data which will be required in order to create the sizing assistance software
7. creation of the sizing assistance software



Example of aeraulics representation:

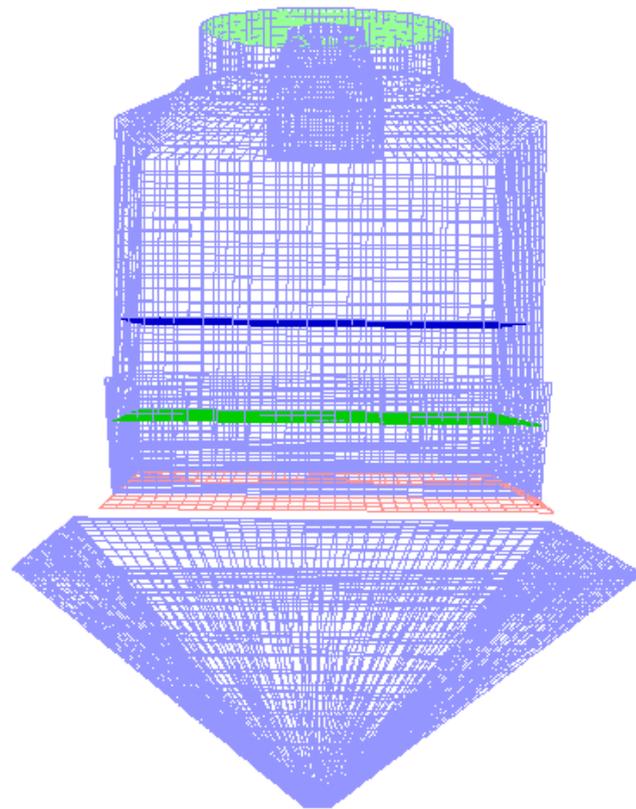


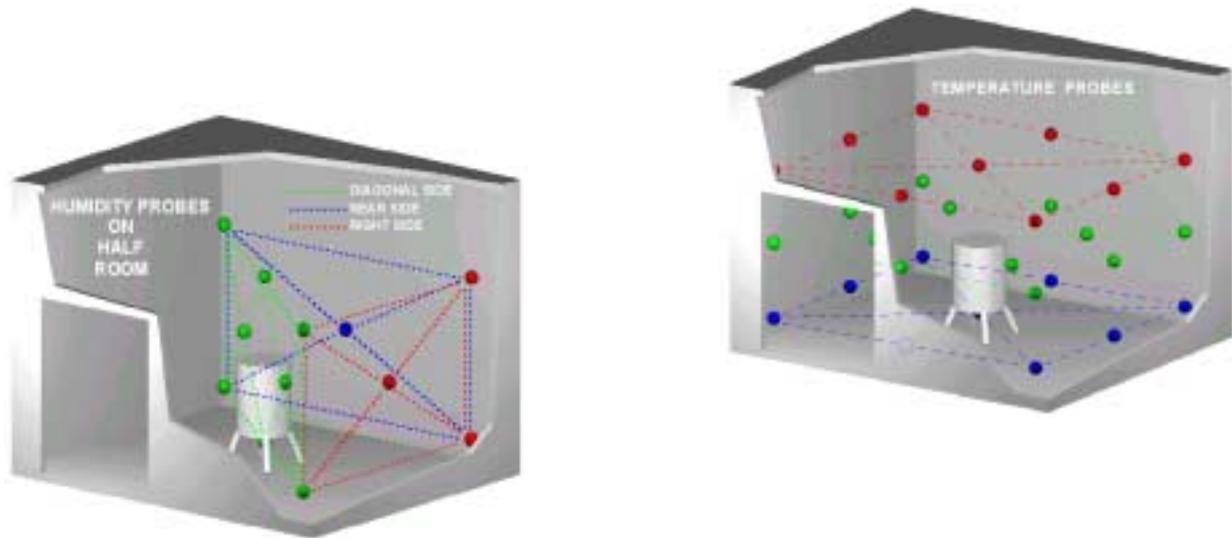
Fig.1 : Caisson prototype (débit d'air 12000m³/h)
Maillage du caisson

5.4. HYGROMETRY

On this topic, the design of humidification equipment was completed to schedule, demonstrating the advantages of using microsonic humidification systems ($<10 \mu$) in order to have a droplet size small enough to avoid deposits thereof being found in the area. Note was also made of the measurement equipment which should be used in conditions of high hygrometry.

The bibliographical work carried out by the Italian partner on certain products (lettuce, fruits with skins), showed lesser weight losses at lower temperature differential levels (between the water in the exchanger and the air needing to be cooled) using an all-or-nothing regulation, when compared with low temperature differentials using a modulation-type regulation.

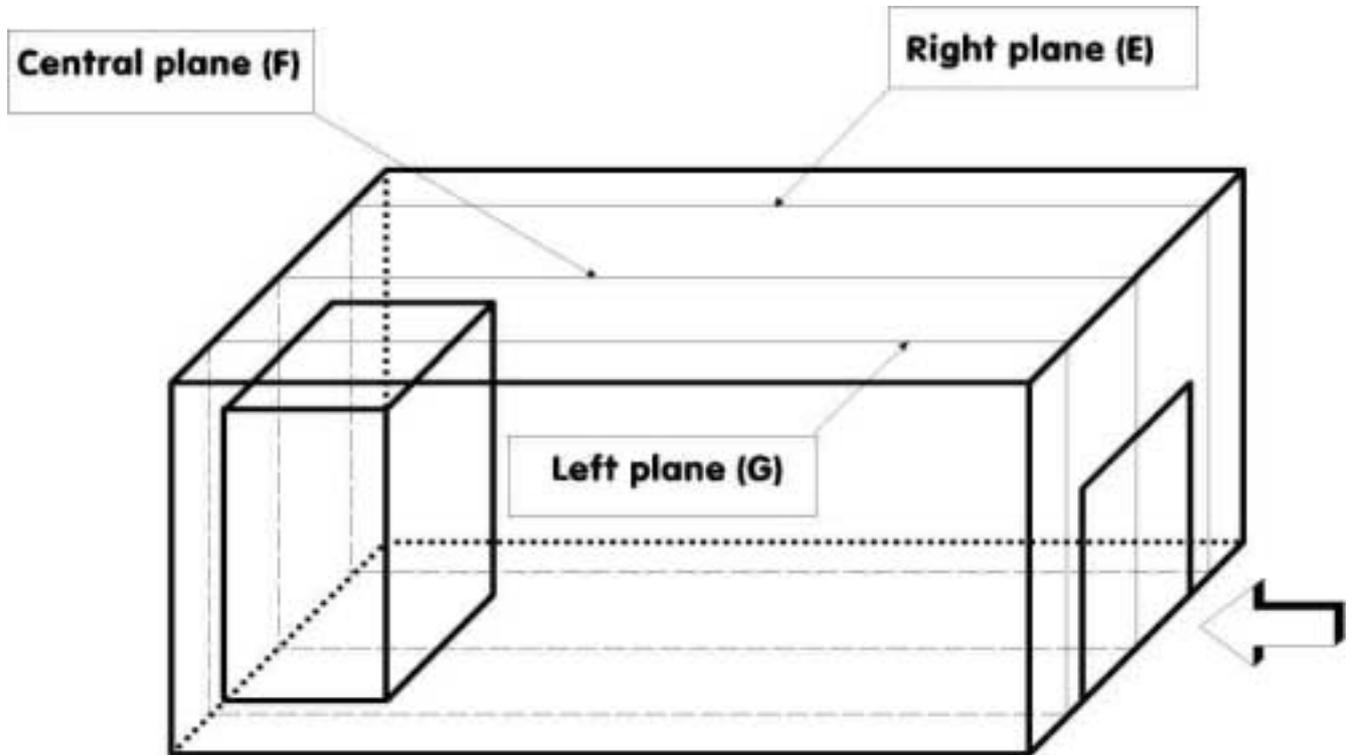
For this reason, we sought to go further with this analysis by looking at the weight loss of 2 sensitive products (2 different types of cheeses), comparing the two regulation variants. If a high temperature differential is used on the latter, the exchanger's performances (and in particular, power ratings) are increased and the cost of the whole system can be reduced (all-or-nothing regulation is cheaper, and the exchanger surface area is smaller).



5.5. THERMIC, HYGROMETRY & AERAULIC TRIALS

More than 30 sensors were used. They were distributed in the trail room following an experimental scheme.

For example, on the tests done



The numerical results are reported in figures: we distribute the results in three planes in horizontal and in vertical. Some graphic representations were made.

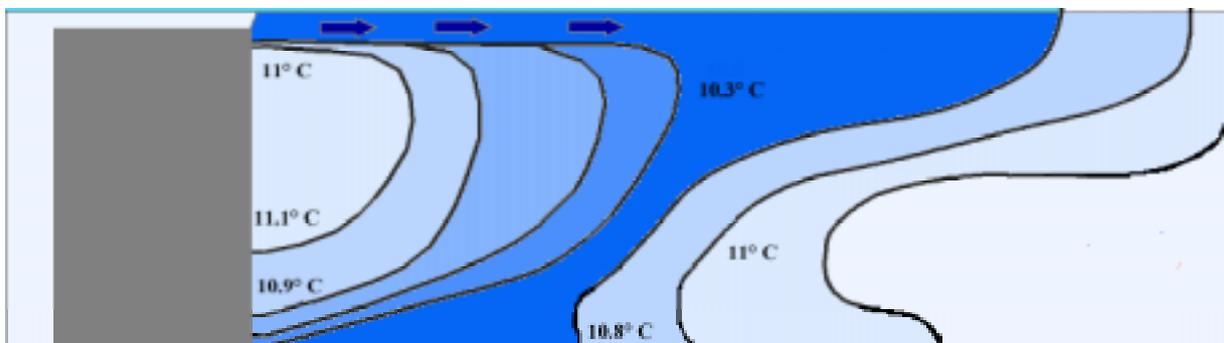
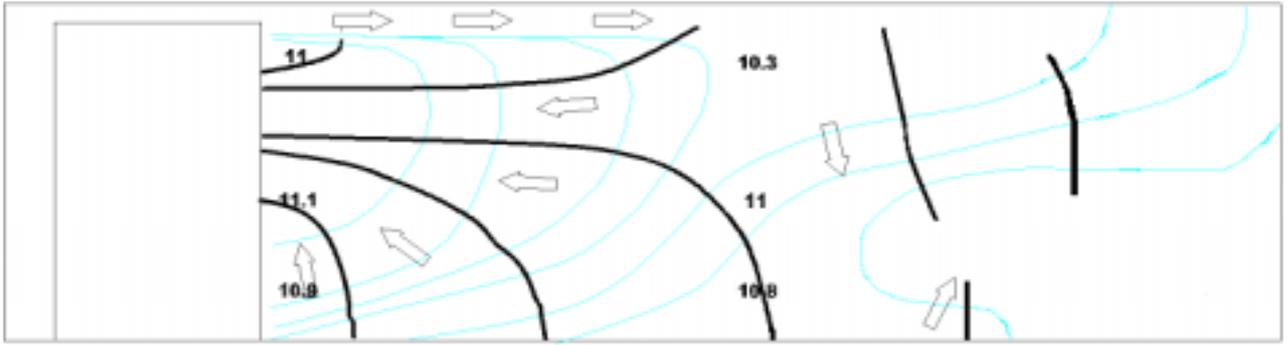


Fig.13: Draft of the isothermal lines in the vertical plane at the middle of the room



5.6. COMPANIES TRIALS

The objective of this task consists to study the effects of air conditioning by stainless still pipe on the evolution of physico-chemical characteristics, on the losses of weight and on quality of Raclette cheese during ripening.

Validation of the prototype efficiency on cheese in industrial conditions (trial 1)

The objective of this task consists in studying the effects of air conditioning by stainless still pipe on the evolution of physico-chemical characteristics, of weight loss and of the quality of Raclette cheese during ripening.

5.6.1 Experimental design

Three hundred cheeses were made during five days and separated into two ripening cellars. The first cellar is the control one: usual regulation (11°C to 11.5°C - 94 % HR), the second one is the trial ripening with air conditioning by stainless still pipe (11°C - 90 to 95 % HR). Cheeses are ripened during 8 weeks and five cheeses from each cellar are analysed under ripening conditions.

5.6.2 Results

Control cheeses have higher weight loss than the trial ones (table 1). The difference between the two ripening conditions is 3.9 points: 3.75 % for trials and 7.63% for controls. Raclette cheese ripened in trial cellar is logically more humid and its pH is less acid (table 2). The average dry extract is 59.7% against 61.3% for control Raclette cheese. This is the direct result of the difference in weight loss between the two ripening conditions. Enzyme activities are thus more intense for trial cheeses that are more humid. However, the proteolysis is not affected by the difference of weight loss and dry matter (table 3), which is not surprising. Indeed, many surveys carried out on Emmental, Comté, and Abondance cheeses have proved that the most influencing parameter on proteolysis is temperature. In our case there is no temperature difference between the two cellars. Moreover, the initial composition of cheeses ripened in control and trial cellars is identical (same producing vat). Those cheeses have a similar potential and there is no reason why proteolysis should be different when ripening is over. Trial cheeses crust aspect is more characteristic than the controls, especially for the colour and visual aspect. The body colour of trial cheese is more yellow, more melting and more elastic than the control ones. This result is directly linked to humidity, which is higher for cheeses ripened in trial cellar.

Table 1: Losses of weight of cheeses during ripening

	Average	Standard deviation
Control	7.63	± 0.83
Trial	3.75	± 0.56

Table 2: Evolution during ripening of physico-chemical characteristics of cheese

	Control		Trial	
	Start of ripening	End of ripening	Start of ripening	End of ripening
pH, pH unit	5.07	5.38	5.09	5.46
Dry matter, %	56.9	61.3	57.3	59.7
Fat in dry matter, %	48.8	48.0	48.6	49.1

Table 3: Evolution of cheese proteolysis characteristics during ripening

	Control		Trial	
	Start of ripening	End of ripening	Start of ripening	End of ripening
TN, g.100 ⁻¹	24.4	25.9	24.7	25.4
SN, g.100 ⁻¹	4.8	7.0	4.6	7.1
NPN, g.100 ⁻¹	1.7	3.8	2.3	3.7
SN/TN %	19.5	27.2	18.6	27.9
NPN/TN, %	7.0	14.8	9.3	14.7

Mould, *Staphylococcus aureus* and total aerobically mesophilic flora are counted before and after prototype cleaning at four places.

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The sampling- is carried out with a swab. Before and after cleaning, the Staphylococcus population is < 10 cfu at the four places of the sampling- (table 4). The other results are presented in table 4. Mould and yeast population is reduced by 100: results are lower or equal to 10 Lfc/cm² after cleaning. The total number of germs does not go beyond 300/cm² after cleaning versus 1,400 for 18,000 ufc/cm² before cleaning.

Table 4: Effect of cleaning with acid solution on the bacteriological content

	Yeast		Mould		S. aureus		TAMPF	
	Before	After	Before	After	Before	After	Before	After
Fan	190	< 10	20	< 10	< 10	< 10	3 400	300
H } Pipe } L }	1 000	10	ND	ND	< 10	< 10	15 000	< 10
	1 000	< 10	ND	ND	< 10	< 10	18 000	10
<u>Vat</u>	60	10	ND	ND	< 10	< 10	1 400	400

TAMPF: Total Aerobically Mesophilic Flora
ND: Non Detected

Conclusion:

To conclude, cheeses ripened thanks to the prototype (air conditioning by stainless still pipe) gives better quality (aspect and body) cheese with a significant reduction of weight loss. The proteolysis of cheeses does not seem affected. An effective cleansing is possible without any difficulty thanks to cleaning acid or, better, by using a disinfectant, for example Peracetic acid.

Trial 2

Confidential results

6. RESULTS & CONCLUSION

We decided to reduce the number of industrial trials, in other words, we decided for thorough and quality trials rather than the foreseen quantity ones. The whole of the foreseen research necessary to designing-, manufacturing, and commercialising the clean heat exchanger has been realised.

The result is that SMEs have today a material hygiene certified with technical and climatic performances digitally determinable for each purpose.

Those performances based upon an hygienic design, precise planning and mathematical models, have been verified and thoroughly checked thanks to the prototype that was co-built by the partners during the project. The various tests did validate the conception and helped adjust the mathematical models;

During the trials, we visualised the climatic performance of the material and as well, we were able to define how to optimise its functioning through changing regulation parameters;

Trials on food products proved very positive as they gave the opportunity to reduce losses on ripening products (7 to 3.5%) and to improve the quality of ripened ones (supple, better crust).

As now, thanks to the European Commission that supported this project, thanks to the chosen partnership, we could do what we imagined initially. SMEs can benefit from a tool meeting their precise requirements.

As for the future, they are willing to go on working together to help each other conquer new markets.

This indirect benefit, which was not initially foreseen, is the direct and obvious result of their hard common work, and therefore the setting up of mutual confidence gained through common objectives and goals. The main interest of the contractor who wanted to develop internationally with safe and sound "relays" has been fulfilled.

The final material is the only equipment in Europe that can boast to have succeeded tests proving its thorough cleanability. Moreover this cleanability gives further guaranty in terms of **food safety** for foodstuffs processed and/or ripened using this material, and, besides, fully meets the consumers' needs on this "hot topic".

We can just add that Mondial Frigo is currently negotiating the sale of some equipment in one single French cheese plant. This is the first (and promising, considering the potential impact of this manufacturer known as innovative direct and very rapid benefit or added value of our successful project, **thanks to our fruitful transnational collaboration.**

7. EXPLOITATION PLAN & ANTICIPATED BENEFITS

With such assets, SMEs foresee to build the equipment (Mondial Frigo & JPS) and commercialise them in their own countries.

In UK, JPS can benefit from Wyatt Air skills whilst in Italy, Mondial will use BARON services and expertise.

For other countries the material will be built by either Mondial or JPS and distribution and commercialisation will be carried out by the company that had the first contact with the customer.

As for today one of the partners is currently negotiating the sale of heat exchangers.

The ambition to commercialise about one hundred machines per year will not be reached the first year but can be reached and further from the 2nd year.

Regarding end users, some companies have already expressed their interest to buy this type of material in the very near future. As initially stipulated in the FAIR agreement, existing between the partners, they will get the material at cost price.

Finally, regarding providers for some spare parts of the machine (regulation, fan, etc.), we agreed on installing their material as a priority as they agree to respect specifications at a competitive price.

8. PICTURES

Air conditioner during hygiene trial



Part of the team at JPS's

(From The left to The right) : Ms LANDY (PEA), MM BROWN (CCFRA), BIDWELL (JPS),
TIMPERLEY (CCFRA), WYATT (WYATT AIR), JOSSERAND (MONDIAL FRIGO)



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Cheeses ripened with ACE



Cheeses in normal ripening

