ESJ Natural/Life/Medical Sciences

Peer-reviewed

Design Proposal of a Smoker-Dryer for Chicken

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Doi:10.19044/esj.2024.v20n18p49

Submitted: 16 March 2024
Accepted: 01 June 2024
Published: 30 June 2024

Cite As:
Guidzavai, A. S., Ndjiya, N., Tchami, J. H., & Njintang, N. (2024). *Design Proposal of a Smoker-Dryer for Chicken.* European Scientific Journal, ESJ, 20 (18), 49. https://doi.org/10.19044/esj.2024.v20n18p49

Abstract

Chicken breeders, particularly those in Ngaoundéré-Cameroon, after 45 days of breeding find themselves confronted with the problem of wasting nutrients and resources. In most cases, they sell their chicken at low prices to avoid expenses. Faced with these difficulties, some of them use various methods to preserve their chicken after 45 days of breeding, including cold preservation, smoking, and drying. Cold preservation is the most widely used technique, but this technique is energy-intensive, without forgetting the untimely power cuts and the deterioration of the quality of the product. By getting closer to its stakeholders, we were able to identify their difficulties and why they use cold preservation more, and they also entrusted us with the characteristics of equipment that could meet their requirements. In this article, we present the results from functional analysis to 3D modeling through the search for solutions to resolve contradictions. It emerges from this study that the model designed guarantees food safety and user safety, retains all nutrients, is ergonomic, uses fewer resources, is fast, and is adaptable to any type and size of the smoking product. We produced the designed model capable of containing 12 chickens, and we carried out the experiments in order to validate the model.

Keywords: Design, smoker, dryer, modelization, Triz

Introduction

Chickens are used as one of the best sources of animal protein for low-income populations and are therefore receiving increasing attention worldwide. The interest in this is booming; it is mainly influenced by the global quest to satisfy the needs of meat products among the inhabitants, which continues to increase. Furthermore, it is well known that there are currently few technical alternatives to meat products for their nutritional contributions to the human body. Hence, the increasing attention devoted to chicken as the best source of animal protein and low-fat.

In Cameroon, and even in the world, the vast majority of the chicken production chain is sold after 45 days of breeding. However, a weak link remains: conservation, given that it is a product with a high water content that decomposes quickly after slaughter. If conservation equipment exists, such as refrigerators, dryers, smokers, etc., they do not allow peaceful processing to take place without altering the quality of the finished product or making consumers and processors sick.

Indeed, cold storage has the disadvantage of being supplied with electrical energy for the entire storage period and of consuming excessive electrical energy. Smoking is hard for those involved in processing, which causes health problems including back pain, burns, eye problems, and common colds. It also degrades the quality of the finished product and consumes enough fuel from leaves, including wood, sawdust, dried dead trees, old cardboard, etc. Drying causes losses of around 50% and a loss of time of around 5 hours to a few days. It is therefore necessary to develop a conservation system guaranteeing food safety and improving conditions for processors.

With this in mind, the main objective of this work is to design chicken smoking-drying equipment, taking into account the requirements of future users. More specifically, we will have to determine the physical properties of chicken meat, analyze the needs, and model the process.

Literature review

Poultry meat is the one whose consumption is increasing the fastest in the world since the 1970s, to the point where it became the most consumed meat in the world in 2016 and helped double global consumption. The FAO estimates that poultry meat consumption is expected to increase by 120% between 2005 and 2050, which can be explained by a demographic effect and an increase in per capita consumption, which would have increased from almost 8 kg/capita at the beginning. of 2000 to nearly 13 kg/inhabitant in 2021.

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Chicken plays a leading role in this evolution thanks to its undeniable advantages, such as accessibility, economic advantages, environmental advantages, absence of religious prohibitions, quality, and nutritional value of products, mainly due to the low-fat content, Senate (2022). Preserving poultry meat or any other meat product in some countries around the world is a challenge due to a lack of electrical power and unexpected power cuts, hence the development of traditional and less expensive preservation techniques such as smoking, drying, salting, frying, fermentation, and many others. Processes such as smoking and indirect drying have a wide variety of physicochemical parameters, thus providing a wider choice to consumers. The many types of smoked-dried foods, such as smoked beef, smoked-dried fish (commonly called Bifaga in Cameroon), etc., are very popular food products, for which this process has made it possible to extend the shelf life and quality and obtain the flavor and texture sought by consumers. Extending shelf life can also affect the nutritional value of foods, such as their vitamin content, CAC/RCP (2009).

Going in the same direction, several studies have emerged in the field of smoking and drying with the aim of improving, ensuring health safety for smoked products, and providing the necessary information linked to a good-quality product. Indeed, according to Vierling (2003), meat is an element that provides proteins because these proteins contain 40% essential amino acids. This food also provides minerals such as phosphorus, iron, etc., as well as vitamins from group B. The lipid content is 1 to 3% in white chicken meat. This is therefore particularly interesting, provided that the skin, which has a high lipid content, is excluded.

For Hamdani (2018), poultry meat represents an essential source of high-quality protein (balanced amino acid content), which gives it significant nutritional value even in small quantities. Poultry meat contains 72.7% water and 26.6% proteins of high biological value. It contains approximately 6% fat in the form of lipid deposits in the skin and inside the abdominal cavity. It also contains mineral elements that are poor in iron but rich in sodium and potassium. The most representative vitamins in chicken meat are vitamins AB, PP, and C. The latter is destroyed during cooking.

Nutritionists agree that the balance of the different fatty acids present in poultry is close to the perfect balance. 25% saturated fatty acids (SFA), 55% monounsaturated fatty acids (MUFA), the latter reducing the level of bad LDL cholesterol, and 20% polyunsaturated fatty acids (PUFA), Roger (2011). However, chicken meat provides appreciable quantities of PUFA, vitamins (B3, B5, B6, B12, etc.), minerals and trace minerals (iron, magnesium, selenium, and phosphorus), and good-quality proteins rich in essential amino acids necessary for muscle growth, particularly in children and adolescents, but also essential for maintaining muscle mass in older people, according to

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Roger (2011). Like all meats, it does not contain carbohydrates. Table 1 below shows the chemical composition of chicken as proposed by Ciqual (2007).

Table 1. Chemical composition of chicken (Ciqual, 2007)

For 100 g of meat	Water (g)	Energy (kJ)	Protein (g)	Lipids (g)	Cholesterol (mg)
Raw thigh, meat, and skin	70	832	17	14.8	90
Roasted thigh, meat, and skin	59	962	26	14.2	122
Raw meat and skin	69	738	18	11.6	80
Roasted meat and skin	66	678	26	6.2	90
Raw white	72	489	22	2.9	61
Cooked white	73	523	22	3.9	71

Materials

Vegetal Material

The strain of chicken chosen is the Gallus Gallus domesticus (commonly called broiler chicken) raised in the town of Ngaoundéré. The birds each weigh approximately 2.5 kg after slaughter and the removal of impurities such as feathers, intestines, and others.

Experimental material

- A tape measure (Stanley 34-295) with a measuring capacity of 10 m;
- A portable digital scale (JMH-JADEVER) with a maximum capacity of 5 kg;
- Module thermometer (9290AT) with a measuring range from -50 to +150 °C.

Methods

Perrin (2001) defines a design method as any procedure or technique used by designers when designing a new product. Regarding our work, we used some tools and methods, such as:

- The 40 principles of invention, which are used to resolve a technical contradiction (when we want to improve a characteristic and another characteristic is degraded simultaneously).
- The 39 parameters of Triz. In fact, the 39 parameters are the characteristics that make it possible to define a technical system. Using the TRIZ matrix, which is made up of 39 parameters, we seek to improve one characteristic while preserving others.

- The 120 suggestions, which are proposed solutions for improving a characteristic without degrading another characteristic, Dumont (2010).
- The Triz method, which is an approved algorithmic approach to solving technical problems.
- Functional analysis is a method used at the start of a project to create (design) or improve (re-design) a product. The principle of the method consists of determining the functions of a product.

In the following lines, we will present some of these methods.

Analyze the need

A product only makes sense if it satisfies the user's needs. In other words, we must clearly pose the problem, i.e., define the why of the product? What is it used for? Who does he serve? And for what purpose? Before imposing a how? Or even a solution, as brilliant as it may be, which will probably not meet the user's needs. The objective of analyzing the need is to grasp, state, and validate the requirements expressed by the actors.

Capture the needs

In this phase, it is a question of making a trip to the field in order to know their needs on an economic, ergonomic, and other level. We can use several tools, including the 5 Whys, survey sheets, etc.

State the needs

This involves rigorously expressing the goal and limits of the study. To do this, the Horned Beast tool can be used to clearly state needs by providing answers to the following questions:

- Who or what does the product serve?
- Who or what does the product work on?
- What purpose?

Validate needs

After having clearly identified the need to be satisfied by the product, it is essential to check its stability. To do this, it is required to find out whether this need is likely to disappear or evolve over a longer or shorter period. This validation check consists of providing answers to the following questions:

- Why does this need exist?
- What can make it disappear or make it evolve?
- What is the risk of making it disappear?

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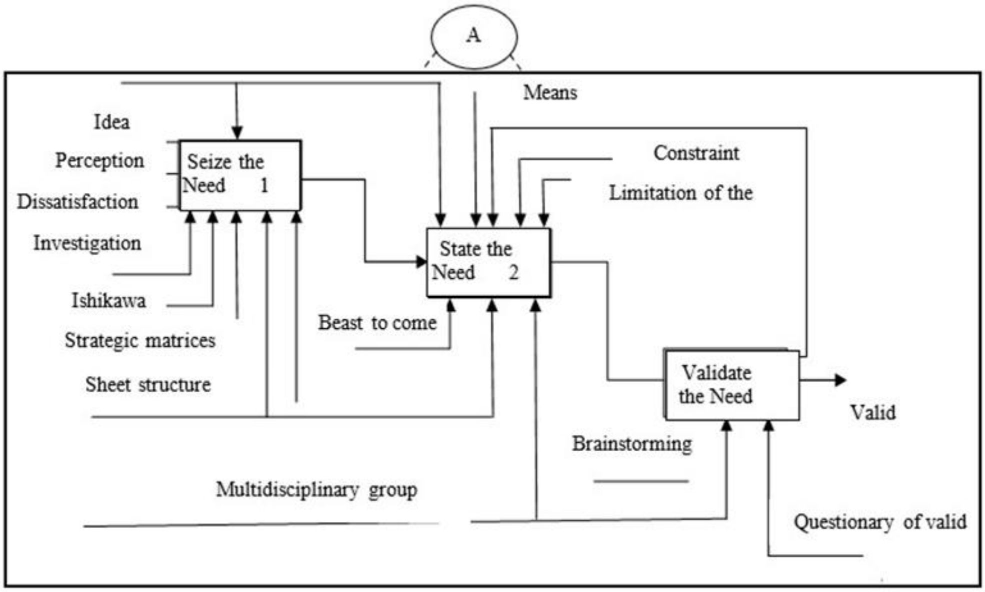

Figure 1. Needs analysis framework

Study the feasibility

It is the functional expression of the need. Indeed, its objective is to establish the Functional Specifications, which we abbreviate by (CdCF). In this phase, it is necessary to identify and explain the satisfaction expected by users of the product. The CdCF is considered a Service Function (SF) generator. It is therefore necessary, at the end of this phase, to identify, characterize, and prioritize the SF.

Identify Service Functions

This involves determining the relationships that external elements maintain with each other through the equipment on the one hand and the interactions they carry out with the environment on the other. The Octopus diagram tool can facilitate the identification of equipment service functions.

Characterize Service Functions

In this phase, the aim is to express the performance of each service function, as expected by the user, that can be collected during the field trip phase (requirements capture). For each function, this will be:

- To state the evaluation criteria for each SF (an evaluation criterion represents a requirement desired by the user), a level defined on a scale adopts the value of the criterion, which is accompanied by flexibility (high tolerance) beyond which the need is declared unmet.
- Define the level of each criterion.
- Match each criterion flexibly.

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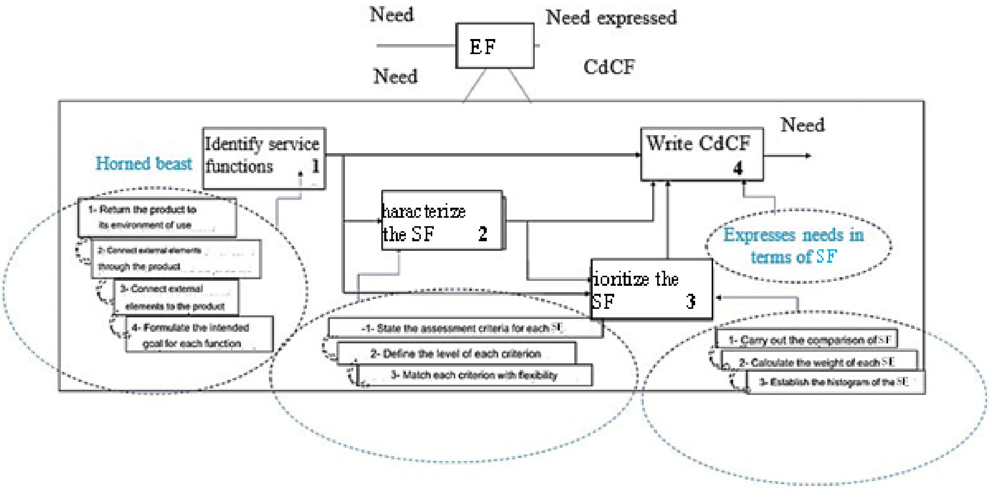
Prioritize Service Functions

This involves comparing functions one by one using a matrix and assigning a score, which can be collected during surveys with future users. Then quantify the weight of each function to establish a histogram to make the prioritization results meaningful.

Figure 2. Feasibility study structure



In this phase, it is:

- Search for ideas and solutions, which consists of transforming all validated service functions into contradictions and reporting them in the contradiction matrix to identify problem-solving principles using the 40 invention principles allowing the resolution of technical contradictions, Dumont (2010).
- Study and evaluate the solutions, which consist of searching for the optimal solution among the 120 suggestions (solutions proposed to improve a characteristic without altering another characteristic) proposed by the 40 principles of inventions, Dumont (2010).

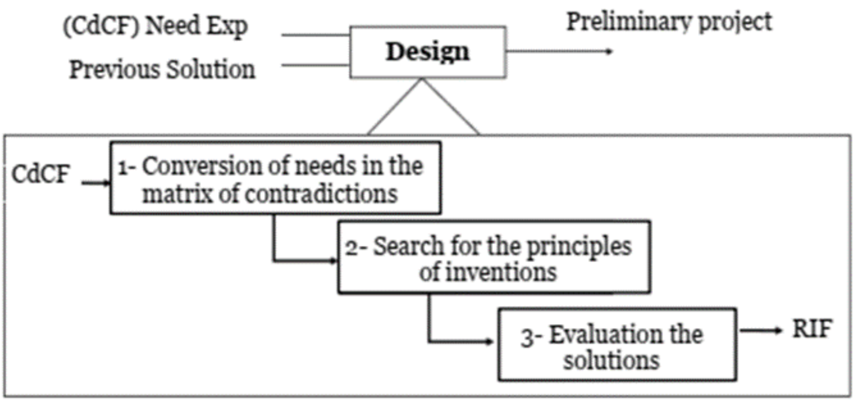


Figure 3. Design structure

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Nomenclatures:

CdCF	Functional specification
SF	Service Function
AB	Needs Analysis
EF	Feasibility Study

Figure 4 below shows the procedure for resolving a technical contradiction.

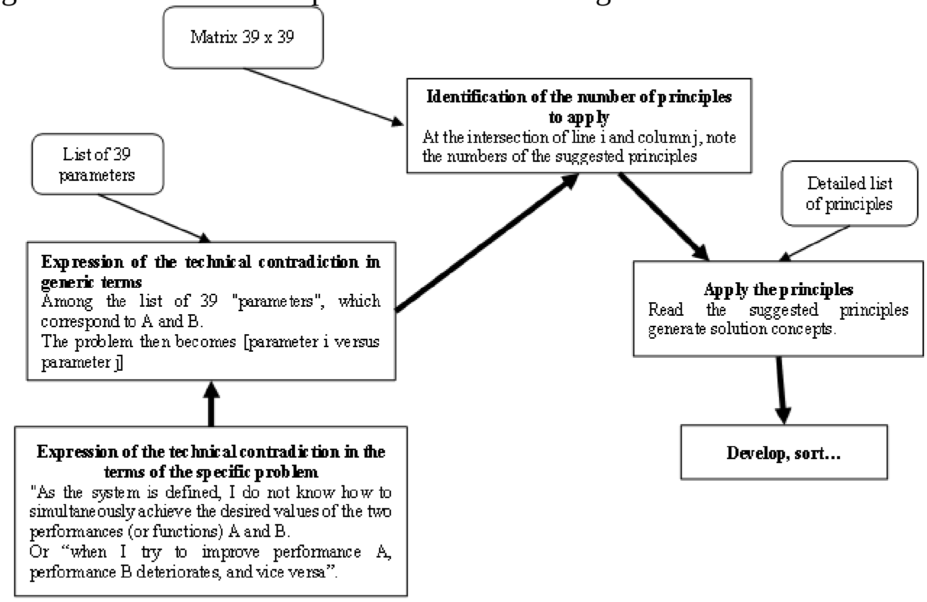

Figure 4. Procedure for resolving technical contradictions (Denis, 2016)

Measurements of physical properties of chickens

Samples of five chickens were chosen at random. For each chicken, we measured their physical dimensions using the tape measure: the length (L), the equatorial diameter (D), and the width (l), which are taken from the neck to the end of the thighs as illustrated in Figure 5, to determine the average physical properties.

Figure 5. Measurement of chicken dimensions

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Interior dimension of the equipment

This involves sizing the prototype of the equipment to be able to contain 10 chickens and for the distribution of air or smoke to be homogeneous. Each bar must contain at least 2 chickens, and the distance between 2 chickens, as well as the distance between the chicken and the walls, must be at least 5 cm.

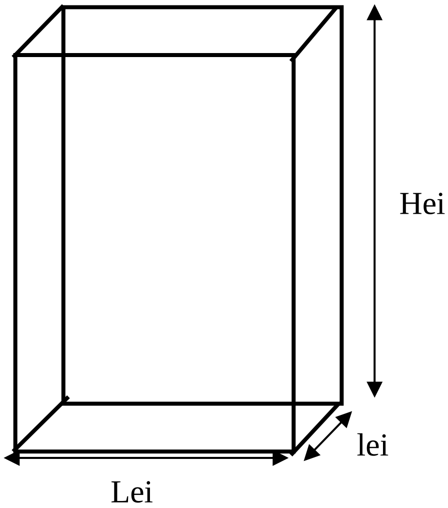

Figure 6. Illustration of the interior dimensions of the equipment

Mass of water to extract

As we know, drying makes it possible to extract a certain quantity of water contained in a product. For Catherine (2003), in order to create the dryer itself, it is therefore necessary to determine the water content of the product before drying (in kg of water per kg of product) and what water content we wish to obtain after drying (in kg of water per kg of product). We therefore have the quantity of water to extract per kilogram (in kg of water per kg of product) of dry air, which is:

$$He = Havs - Haps \quad (1)$$

By multiplying by the total mass of product (in g of product) that can be filled in a dryer, we obtain the total quantity of water to be extracted by the dryer (in g):

$$Me = He.Mp \quad (2)$$

Useful power is required to extract this quantity of water

This is the power necessary to extract a quantity of water. This power, which will have to evaporate the humidity contained in the bagasse, is obtained by the following relationship, proposed by Jean-François in 1995:

$$Pe = \frac{Me.Lv}{t} \quad (3)$$

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With:
- Pe: power to extract Me kg of water in kW;
- Me: mass of water to be extracted in kg;
- Lv: latent heat of evaporation of water (KJ/kg);
- t: drying time per cycle in seconds (set at 1 hour);

Calculation of the power of the air that will be blown into the dryer
The formula for calculating this power was given by Jean-François in 1995:

$$Pa = Qm.1013,6.(Tint - Text) \quad (4)$$

With:

$$Qm = \frac{W}{YS-YE} \text{ and } W = \frac{Me}{t} \quad (5)$$

- YS: indoor relative humidity (%);
- YE: outdoor relative humidity (%);

The air conditions outside and inside the dryer were measured using the thermometer module.

Table 2. Air conditions

Parameters	External conditions (Adamaoua region)	Internal conditions (allowable value)
Temperatures (°C)	T_{ext}=22	T_{int}=75
Relative humidity (%)	YE=85	YS=95

Calculation of thermal losses through walls
Side walls

Table 3. Calculation of losses through side walls

Elements to calculate	Formula	Data	
Side surface (m²)	S = 4.Hei.lei	Height = Hei(m)	0,60
		Width = lei(m)	0,45
Materials		Wood panels	Aluminum sheet
Conductivity (W/mK)		0,014	230
Thickness(m)		0,07	0,0003
Thermal resistance	$R_{th} = 1/h + e_1/\lambda_1 + e_2/\lambda_2$		
Convection coefficient (h_{in})	h_{in}	5	
Overall coefficient (K)	$1/ R_{th}$		
Temperature Difference (°C)	$T_{int} - T_{ext}$	T_{ext} = 22	T_{in} = 75
Heat flux (kW)	$K.S. (T_{in} - T_{ex})$		

Top and bottom walls of the dryer

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Table 4. Calculation of heat losses through the top and bottom of the dryer

Elements to calculate	**Formula**	**Data**	
Side surface (m^2)	S = 4.Lei.lei	Length = Lei(m)	0,65
		Width = lei(m)	0,45
Materials		Wood panels	Aluminum sheet
Conductivity (W/mK)		0,014	230
Thickness(m)		0,07	0,0003
Thermal resistance	$R_{th} = 1/h + e_1/\lambda_1 + e_2/\lambda_2$		
Convection coefficient (h_{in})	h_{in}	5	
Overall coefficient (K)	$1/ R_{th}$		
Temperature Difference (°C)	$T_{int} - T_{ext}$	$T_{ext} = 22$	$T_{int} = 75$
Heat flux (kW)	$K.S.(T_{int} - T_{ext})$		

Unquantifiable losses

We will consider that these losses correspond to 10% of the useful power.

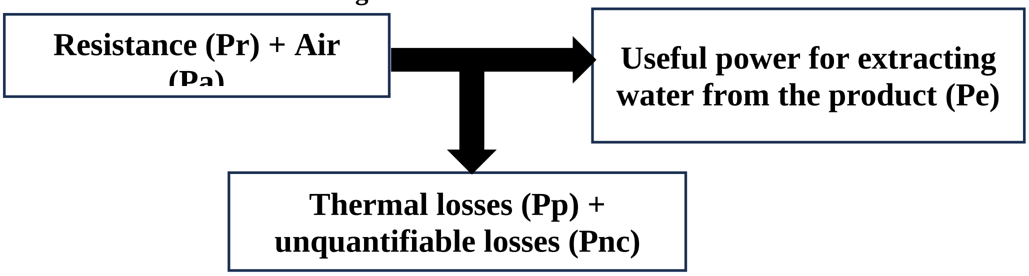
$$Pnc = Pa.0,1 \quad (6)$$

Power of heating resistors

Heat balance in the dryer

The following figure 7 presents the procedure for calculating the heat balance in the dryer:

Figure 7. Thermal balance



From this procedure, we can deduce the power of the heating resistance by using the expression:

$$Pr = Pe + Pp + Pnc - Pa \quad (7)$$

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Results Analysis of the need

Entering needs

Following a field trip (a survey of breeders and restaurant managers in the town of Ngaoundéré-Cameroon), we present here some primary needs of stakeholders in terms of equipment for preserving meat products:

- No more than 3 hours of transformation time per cycle;
- Transform product sizes ranging from 10 to 2000 per cycle;
- The finished product must be tender and not too dry;
- Very economical in terms of fuel and energy consumption;
- Affordable price/quality ratio;
- No exposure to heat or smoke;
- Improve product quality (especially broilers);
- No loss of information.

Statement of needs

The smokehouse-dryer should allow breeders to preserve chickens for long-term availability and without risk of bacteriological contamination after consumption. Figure 8 is an illustration of stating needs using the horn tool.

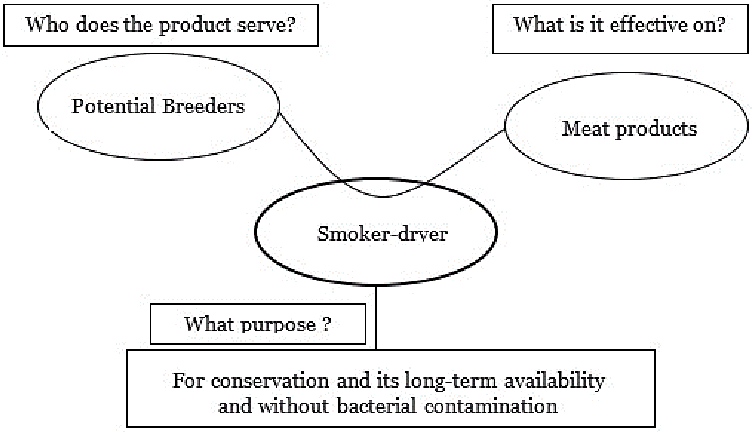

Figure 8. Statement of needs

Validation of needs

- It is for the conservation and availability of chickens while guaranteeing good hygiene that this need exists. This would allow a reduction in poverty in general.
- When farmers can satisfy the current market without keeping the chickens, then the equipment can disappear.
- The increase in the human population leads to the evolution of the product.

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- By making the product disappear, we will probably see an increase in the cost of purchasing chicken, its difficulty in obtaining it, and an increase in poverty.
- By developing it, we can witness the popularization of chicken in our markets, like that of fish, and a considerable reduction in purchasing costs. So, there is a reduction in poverty in the general case.

Feasibility study

Identification of service functions

Figure 9 shows how external elements interact with each other through the smoker-dryer and how they interact with the environment using the Octopus diagram tool. The main function that the equipment must fulfill is to be able to extract water efficiently from meat products.

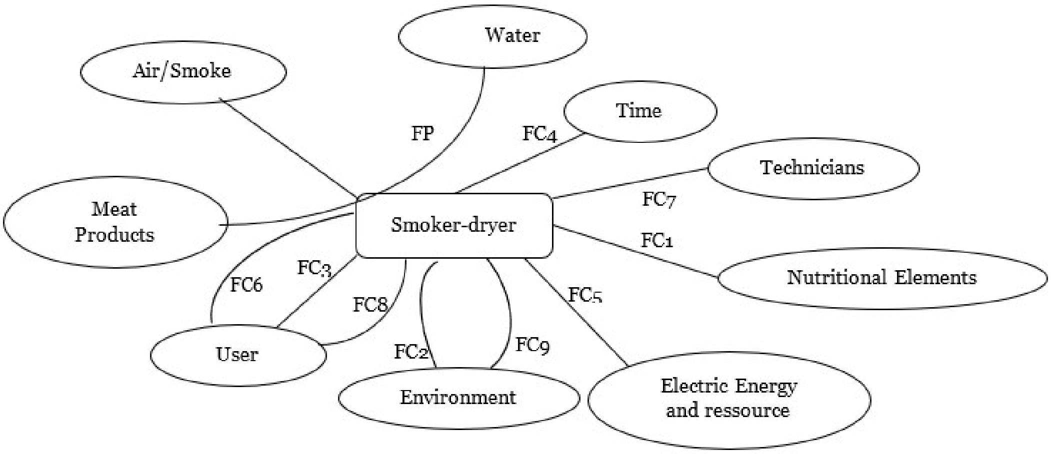

Figure 9. Identification of service functions

Characterization of Service Function

The equipment must, above all, fulfill its primary function, which is to extract water efficiently from meat products. The assessment criteria are based on the quantity of water remaining in the meat product, which must never exceed 30% of which they can continue to dry naturally in the open air, and the extraction speed, which must not exceed 3 hours. In addition, the finished product leaving the equipment must not have any trace of polycyclic aromatic hydrocarbons (PAH) and must not consume more than 200 watts per hour. Table 5 represents the characterization data of the service functions, their assessment criteria, and their level of flexibility.

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Table 5. Characterization of service functions

Function	State	Appreciation criteria	Flexibility level
Primary function (FP)	Extract water from meat products	The amount of water remaining	0 to 30%
		Extraction speed	No more than 3 hours per cycle
Constraint function N°1 (FC1)	Protect the product from bacteria	The number of bacteria present and their quantity	0
		Quantity of dust and ashes	None
		Quantities of PAHs	None
Constraint function N°2 (FC2)	Retain product nutrients	Percentage of nutrients lost	Less than 5%
Constraint function N°3 (FC3)	Ergonomic	• Smoke leak • Exposure to fire • User supervision and control	• Negligible • None • Just the initial setup and remote control
		Number of operations to be performed by the user	1
		Protection of users against	Yes
		Overheating and electrocution	
Constraint function N°4 (FC4)	Fast	Duration of a transformation cycle	No more than 3 hours
Constraint function N°5 (FC5)	Use a small amount of electrical energy and a small amount of sawdust needed	Amount of energy consumed per cycle	No more than 200W per hour
		Sawdust volume for one cycle	5L per cycle
Constraint function N°6 (FC6)	Configure operating parameters	Difficulty level	Very easy
Constraint function N°1 (FC7)	Be easy to troubleshoot	Difficulty in disassembly, assembly, and identification of circuit blocks	Easy
Constraint function N°8 (FC8)	Resist the ambient environment	Bearable operating temperature	Up to 450°C
		Resist water	Yes
Constraint function N°9 (FC9)	Aesthetic	Attractiveness	Average

Prioritization of Service Functions

Table 6 below represents the hierarchy of service functions. From this table, we can clearly identify that the priority function is the primary function (FP), followed by the constraint functions FC1, FC2, FC3, and FC5. The most

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minor priority functions are the FC9 functions, followed by the FC6 and FC8 constraint functions.

Table 6. Identification of service functions

	FC1	FC2	FC3	FC4	FC5	FC6	FC7	FC8	FC9	Pts	%
FP	0	1	3	3	3	3	3	3	3	22	22,22
	FC1	1	2	3	3	3	3	3	3	21	21,21
		FC2	2	3	3	3	3	3	3	20	20,2
			FC3	2	1	3	1	1	2	10	10,1
				FC4	0	3	0	0	1	4	4,04
					FC5	3	2	2	3	10	10,1
						FC6	1	0	2	3	3,03
							FC7	2	3	5	5,06
								FC8	3	3	3,03
									FC9	1	1,01
									Total	99	100

Design

Matrix of contradictions

We present in Table 7 the conversion of the service functions into contradictions, which we report in the Triz contradiction matrix. In fact, by wanting to improve the temperature in the product to extract the water quickly, we see a loss of substance and the deterioration of the quantity of material, or substance and productivity. The resolution of its contradictions is possible through the application of one or a combination of these principles: 3, 17, 15, 21, 28, 29, 30, 31, 35, 36, and 39.

Table 7. Matrix of contradictions

Deteriorates / Improves	Resistance	Waste of energy	Loss of substance	Waste of time	Quantity of material/substance	Productivity
Strength (Intensity)	35, 10, 14, 27					
Resistance				29, 3, 28, 10		29, 35, 10, 14
Temperature			21, 36, 29, 31		3, 17, 30, 39	15, 28, 35
Energy spent by the moving object						12, 28, 35
Loss of substance	35, 28, 31, 40					
Loss of information		19, 10		24, 26, 28, 32		13, 23, 15
Harmful factors acting on the object			33, 22, 19, 40			22, 35, 13, 24
Productivity						

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Search for ideas and solutions

The search for ideas and solutions consists of searching for the optimal solution among the suggestions offered by the principles of inventions retained. In our case, we instead made a combination of several suggestions, among which we can cite:

- Make each part of an object operate in the most appropriate conditions for its operation, thanks to principle 3, which is the principle of local quality;
- Reverse the actions used to solve a problem obtained from principle 13, which is the principle of inversion;
- A multi-story object layout instead of a single-story. Use a multi-layer assembly of objects instead of a single layer, as proposed by principle 17, which is the principle of another dimension;
- Replace an expensive object with several inexpensive objects that have certain qualities (such as lifespan, for example) of principle 27. Replace a typical environment with an inert environment following the study and evaluation of the suggestions of principle 39, which is the principle of the inert atmosphere.

Physical properties of chickens and internal dimensions of equipment

Table 8 opposite lists the interior dimensions of the equipment as well as the average physical properties of the chickens.

Table 8. Interior dimensions of the equipment

	Physical properties of chickens	**Internal dimension of equipment**	**Dimensions of bars**
Length	L = 25 cm	Lei = 65cm	Lb = 65 cm
Width	L = 15 cm	lei = 45cm	
Height		Hei = 60cm	
Diameter	D = 13 cm		Db = 3 cm
Material		Aluminum sheet of 0,3 mm + wood panels	Stainless steel

Equipment feature

Table 9 opposite lists the characteristics of the equipment:

Table 9. Equipment specifications

Category	**Designation**	**Value**
Vegetal material	Mass of water to extract (HE)	60%
	Total quantity of water to be extracted per cycle (Me)	18000 g
Fan	Power required to extract the quantity Me of water (Pe)	11,25 kW
	Evaporative flow (W)	0,005 kg/s
	Dry air mass flow (Qm)	0,0005 kg/h
	Power of the air that will be blown into the dryer (Pa)	0,027 kW

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Thermal losses	Losses through the side walls and losses through the top and bottom walls of the dryer (Pp)	11,4 W
	Unquantifiable losses (*Pnc)*	1,125 kW
Heat resistance	Power of the heating resistance (Pr)	12,35 kW
Heat conductor inside the dryer	Aluminum sheet	0,3 mm

Model of the equipment

Following the search for optimal solutions among the suggestions proposed by the 40 principles of invention as presented by the author Denis (2016), we provide in Figure 10 one of the 3D models designed by integrating the service functions and the requirements of the actors.

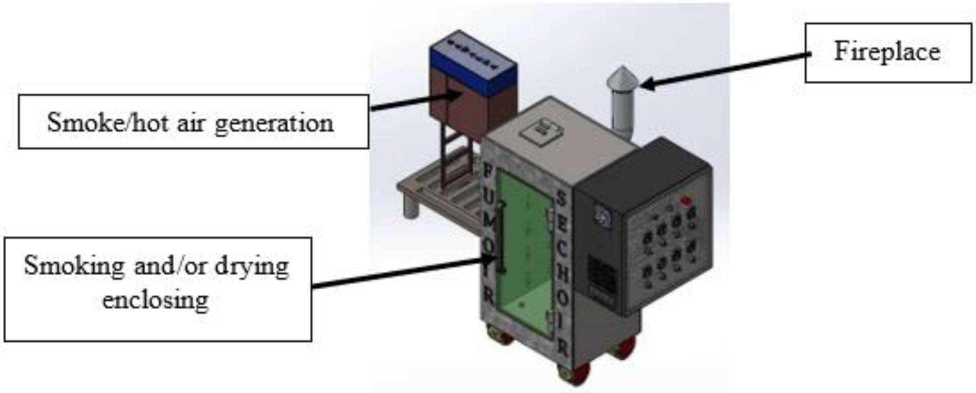

Figure 10: 3D smokehouse-dryer model

Heat flow simulation

Figure 11 illustrates the heat flow simulation in the 3D model. We can clearly observe that the heat flow is homogeneous at all points in the smoking/drying chamber.

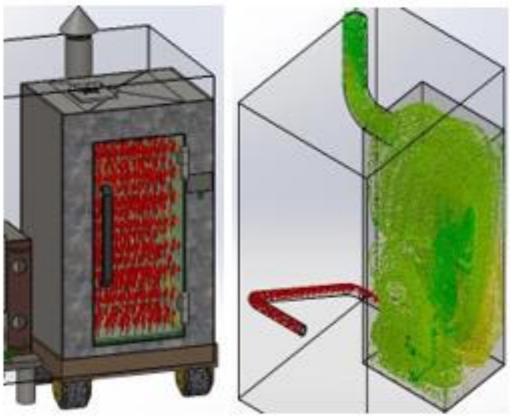

Figure 11. Simulation of heat flow in the 3D model

 ISSN: 1857-7881 (Print) e - ISSN 1857-7431

Conclusion

Having reached the end of our work, remember that we analyzed the needs and proposed a 3D model of the equipment. In doing so, we first, in this document, captured and stated the needs of chicken breeders and restaurateurs in the city of Ngaoundéré-Cameroon, which were then validated. We then identified the service functions, which were characterized and prioritized. Characterization and prioritization allowed us to seek ideas and solutions for equipment design, integrating previously captured customer needs. We then sized the prototype to be capable of processing 10 chickens, each weighing 2.5 kg. From this study, it appears that it is possible to integrate the needs of stakeholders into the design and construction phases using the Triz method. The realization and the experiments were carried out with the aim of verifying whether all the requirements were taken into account. And the smoking-drying of a 38-day-old broiler weighing 1.68 kg after plucking and cleaning was transformed into 4 hours of time under a temperature of 57 °C at an air speed of 1 m/s for a final mass of 0.4 kg. It will be interesting to carry out several experiments by varying the temperature and speed of the air.

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Acknowledgments

This work was supported by the Institut de la Francophonie pour le développement durable (IFDD/Canada) /Projet de Deploiement des Technologies et Innovations Environnementales (PDTIE) funded by the Organisation International de la Francophonie (OIF), the Organisation of African, Caribbean and Pacific States and the European (EU) (FED/220421-370). We offer our deep gratitude to PEPITA-UN for its constant support, its multifaceted encouragement and its teachings which continually sow the spirit of innovation and SciencePreneur. I would like to thank my scientific sponsors, and my fellow researchers for their support, as well as for their constructive comments, lively debates, and helpful critiques, whose varied points of view have considerably improved this work.

Funding: This work was supported by PEPITA-UN UN (Projet d'Excellence en production d'Innovations Technologiques en Agro-Industrie de l'Université de Ngaoundéré).

Conflicts of Interests: The authors reported no conflict of interest.

Data availability: All data are included in the content of the paper.

Ethical declaration: This study has been approved by PEPITA- and the principles of the Helsinki Declaration were followed.

 ISSN: 1857-7881 (Print) e - ISSN 1857-7431

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