applied sciences

MDPI

Article

The Investigation of Key Factors in Polypropylene Extrusion Molding Production Quality

Dyi-Cheng Chen, Der-Fa Chen *, Shih-Ming Huang and Wen-Jye Shyr *

Department of Industrial Education and Technology, National Changhua University of Education, No. 1, Jin-De Road, Changhua 500, Taiwan; dcchen@cc.ncue.edu.tw (D.-C.C.); hsm2014y@gmail.com (S.-M.H.)
* Correspondence: dfchen@cc.ncue.edu.tw (D.-F.C.); shyrwj@cc.ncue.edu.tw (W.-J.S.)

Abstract: This study took food-grade polypropylene packaging products as the research project and discussed how to control the polypropylene extrusion sheet thickness and vacuum thermoforming quality and weight. The research objective was to find the key factors for reducing costs and energy consumption. The key aspects that may influence the polypropylene extrusion molding quality control were analyzed using literature and in-depth interviews with scholars and experts. These four main aspects are (1) key factors of polypropylene extrusion sheet production, (2) key factors of the extrusion line design, (3) key factors of polypropylene forming and mold manufacturing, and (4) key factors of mold and thermoforming line equipment design. These were revised and complemented by the scholar and expert group. There are 49 subitems for discussion. Thirteen scholars and experts were invited to use qualitative and quantitative research methods. A Delphi questionnaire survey team was organized to perform three Delphi questionnaire interviews. The statistical analyses of encoded data such as the mean (M), mode (Mo), and standard deviation (SD) of various survey options were calculated. Seeking a more cautious research theory and result, the K-S simple sample test was used to review the fitness and consistency of the scholars' and experts' opinions on key subitem factors. There are ten key factors in the production quality, including "A. Main screw pressure", "B. Polymer temperature", "C. T-die lips adjustment thickness", "D. Cooling rolls pressing stability", "E. Cooling rolls temperature stability", "F. Extruder main screw geometric design", "G. Heating controller is stable", "H. Thermostatic control", "I. Vacuum pressure", and "J. Mold forming area design". The key factors are not just applicable to classical polypropylene extrusion sheet and thermoforming production but also to related process of extrusion and thermoforming techniques in expanded polypropylene (EPP) sheets and polylactic acid (PLA). This study aims to provide a key technical reference for enterprises to improve quality to enhance the competitiveness of products, reduce production costs, and achieve sustainable development, energy savings, and carbon reductions.

Keywords: Delphi technique; extrusion molding; key factors; polypropylene; production quality

check for updates

Citation: Chen, D.-C.; Chen, D.-F.; Huang, S.-M.; Shyr, W.-J. The Investigation of Key Factors in Polypropylene Extrusion Molding Production Quality. *Appl. Sci.* **2022**, *12*, 5122. https://doi.org/10.3390/app12105122

Academic Editor: Sergio Torres-Giner

Received: 23 April 2022
Accepted: 18 May 2022
Published: 19 May 2022

1. Introduction

The prevalence of COVID-19 has severely impacted economic activities and common people's lives worldwide [1]. The anti-epidemic measures have made many restaurants use portable food packages. When the epidemic situation became severe in 2021, many restaurants or shops stopped their dine-in services for epidemic control. Some stores went further to provide takeaway in disposable food packaging containers only. They refused to put food in the environmentally friendly containers of the customers. The epidemic prevention and environmental protection issues fall into a dilemma [2].

Most food packaging containers in the world are plastic and composite paper packaging materials. The annual consumption of different kinds of beverage paper cups in Taiwan is estimated at more than 2 billion pieces. According to the investigation of Greenpeace International in 2021 [3], it is hard to estimate the quantity increase during the COVID-19 pandemic. The issue of plastic reduction has been the trend and consensus of environmental protection globally [4]. In 2019, the European Union appealed to reduce the use of single-use plastics (SUP). They proposed the single-use plastics-related policy (EU) 2019/904 and SUP instruction. The EU required the member states to prohibit using some single-use plastics products since July 2021, which were generally regarded as the most familiar marine garbage [5], mostly dinnerware and beverage packing containers. To reduce pollution in the transition period, scientific methods are required to control the source, increase manufacturing efficiency, improve quality, and reduce the weight of products. There are many environmentally friendly materials for substituting plastic raw materials, especially the alternative products of biomass material [6] or degradable plastics [7]. However, there are problems in sanitary preservation and the pollutant plastic recycling system to be overcome, for example, using the biomass material polylactic acid (PLA) [8] to replace some plastic packaging materials for food. The replacement of material is not a radical solution. It can be confused with the existing plastics recycling system in Europe, e.g., polyethylene terephthalate (PET), resulting in more pollution and losses.

This study suggested that environmentally friendly disposable food packaging containers should be a simple material, recyclable, or biodegradable. In compliance with the global trend of plastic reduction [9], the UK government collects a plastic packaging tax. It implements the deposit return scheme (DRS), which directly collects petty environmental protection deposits from beverage manufacturers while encouraging them to be involved in recycling. As the name suggests, extended producer responsibility (EPR) extends the producers' responsibility [10], meaning that relevant manufacturing enterprises bear all expenses related to recycling and processing packages. To ensure the recycling of more plastic products is a scientific and feasible method, Lavoisier, a French chemist, proposed the "law of conservation of matter" in 1787 [11]. He stated that industrial products consume energy, and the environment will be inevitably polluted. The merits and demerits should be discussed using scientific and objective methods. How to reduce the resource consumption and pollution resulting from developing and manufacturing plastic packaging containers is the actual aspect conforming to the "plastic reduction" reality. This study discusses assisting enterprises to develop more conveniently recyclable and environmentally friendly plastic products, enhancing key technologies and manufacturing machines and molds for high-efficiency bulk production, meeting the demand for market competition cost and finding quality improvement methods.

The current recyclable materials development focus in Europe is mainly on polypropylene (PP) [12]. It is characterized by a higher impact resistance, robust mechanical properties, resistance to multiple organic solvents, and resistance to acid/alkaline corrosion. It is extensively used in food containers (routine food containers), such as meal boxes and beverage cups. The food-grade PP container is free of oral toxicity, and it will not increase the probability of getting cancer. The productivity of PP is expected to be increased by almost six times in 2024. Therefore, PP is a relatively ideal and environmentally friendly and recyclable food packing material among the present plastics [13].

This study used food-grade PP as a raw material in the production of extrusion sheets and food packaging containers of vacuum thermoforming and discussed how to control quality factors. The key factors of production quality can be obtained from the research. The results are analyzed by sophisticated PP production techniques and manufacturing machines and molds. This provides a reference for academic discussion or the development of automatic intelligent machines and technical enhancement. The intelligent automated machine production and quality control can obtain some suggestions or conclusions. The quality of recyclable plastic products can be further upgraded, and the enterprise cost can be reduced. This can further help environmental protection, energy savings, carbon reductions, and sustainable operations.

The purposes of this study are concluded as follows: (1) to probe into the key technology of producing PP extrusion sheets and molded products, to find the important influencing factors in stable production quality, to provide some suggestions or opinions, and to provide references for the researchers and managers of related production techniques; (2) to provide some key advantageous factors in designing and manufacturing special machinery equipment and molds, to provide innovative directions for business circles to improve and develop intelligent machinery and mold equipment; and (3) to discuss the reference indicators of upgrading quality and reducing the production cost for enterprise managers to improve technology and business performance.

2. Literature Review

2.1. Polypropylene

Polypropylene [14] is derived from the reaction of petrochemical propylene gas with a density of 0.89–0.94 g/cm^3. It is a lightweight plastic material with a semitransparent white color and has a lower cost than other plastic materials. It is also one of the recyclable plastic materials. In 1954, Italian chemist Giulio Natta successfully synthesized low-molecular-weight PP [15]. PP is a thermoplastic that is polymerized of propylene monomers, which are resistant to −20–120 °C. Its melting point is 145–162 °C, which is higher than HDPE [16]. Food packaging containers made of PP can be sterilized by steam. It has higher impact resistance and is resistant to multiple kinds of organic solvents and acid/alkaline corrosion. PP is the second largest polymer plastic in Europe. It accounted for 19.1% of the plastic output of the European Union in 2015 [17] and accounts for 21% of global production output [18]. PP is resistant to acid, alkali, and high temperatures (100–120 °C). Therefore, it is extensively used for food packaging containers. Food manufacturers pay attention to packages' thermal performance or temperature requirements [19]. They generally use PP plastic raw material containers to protect the consumers' food safety and health. Due to the COVID-19 pandemic, wearing a mask has become a basic consensus in epidemic prevention worldwide [20]. The primary material of non-woven fabrics for masks is PP, and one mask uses about 4 g of PP raw material [21]. Medical masks and protective clothing are closely related to PP.

The sample of the purpose for this study is producing coffee cup lids of polypropylene material, as shown in Figure 1. The features of the chosen material are different, as shown in Table 1. Although it is general purpose, the object uses polypropylene homopolymer as a material with several features [22]: (1) high transparency, (2) good moldability, (3) high stiffness, and (4) high heat deflection temperature. Recently, newly developed expanded polypropylene (EPP) sheets, in the place of expanded polystyrene (EPS), are used generally in the automobile industry [23]. Furthermore, although the additives or agents in the extrusion process for expanded or non-expanded polypropylene sheets have different uses [24], the key factor of product quality control stays the same. Similarly, the processes of vacuum forming and mold design for both are different as well. Expanded polypropylene sheets for food packaging can achieve less material usage, better isolation purpose, and higher heat resistance under the slight changing in the parameter setting on the basis of their different shrinkage ratio. As long as changing the extruded die and cooling mandrel, etc. is a key factor, it can also achieve the good result in production quality control to use isobutane or CO_2 as a blowing agent injected in the extruder to increase the foaming ratio under the physical foaming process, as shown in Figure 2 [25]. The study can correspond to the key factor in the quality of thermoforming processing. Many manufacturers stopped producing foamed (Styrofoam) food containers due to the prohibited policy in Taiwan in July 2022, so no further explanation in expanded polypropylene was needed.

Figure 1. Polypropylene coffee lid with molds.

Table 1. Properties of raw materials for producing polypropylene coffee cup lids.

Selection of Reference Values for Raw Material Properties			
Typical Property	**Test Method**	**Unit**	**Reference Value**
Melt flow rate (230 °C, 2.16 kg)	ASTM D1238	g/10 min	1.6 ± 0.1
Density	ASTM D792	g/cm^3	0.901 ± 0.001
Tensile strength at yield	ASTM D638	kg/cm^2	370 ± 10
Flexural modulus	ASTM D790	kg/cm^2	15,500 ± 1000
Rockwell hardness	ASTM D785	R scale	100 ± 5
Heat deflection temperature (4.6 kg/cm^2)	ASTM D648	°C	105 ± 2
Izod impact strength, notched 23 °C	ASTM D256	kg-cm/cm	5.0 ± 0.5
Mold shrinkage	ASTM D955	%	1.5 ± 0.1

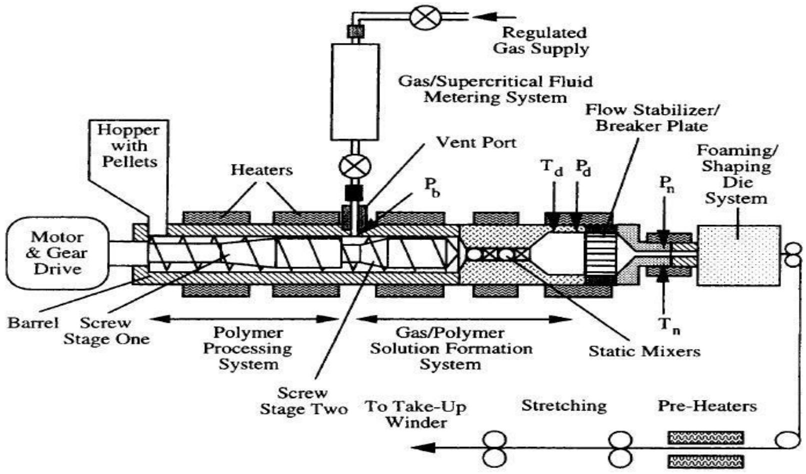

Figure 2. The schematic of polypropylene physical foaming process (Reprinted with permission from Ref. [25]. Copyright 2022, Chen and Lin).

2.2. Extrusion Molding

Extrusion vacuum forming [26,27] is a standard plastic heating method. The granular or sheet polymer material of a plastic fiber is heated and melted by an extruder [28]. After the extrusion sheet is obtained, the plate [29] or sheet skin material roll of the melt is continuously heated by a mold [30] or molding module or vacuum pressed [31]. After cooling modeling, the plate or sheet skin is then cut into plastic products.

In recent years, constant innovative techniques to develop special-purpose machines with higher demand in the market for food containers continuously keeps going. The machine, as shown in Figure 3 [32], for mass production in extrusion in-line with a thermoforming system reduces the heating time in the heat tunnel before sheets in the forming process to raise the cycle time, increase efficiency, and decrease energy consumption in manufacturing, leading to cost savings. In the meantime, intelligent control systems and robotic arms conducted in automatic machinery lessen the risk of operation error and manual movement. This achieves manpower savings, increases operator safety and reduces the risk of accident. Currently the product process of a polypropylene in-line system is extrusion connected with a thermoforming machine, such as a cut-in-mold thermoforming machine, and further in connection with an automatic regrind recycling system, as shown in Figure 4 [33].

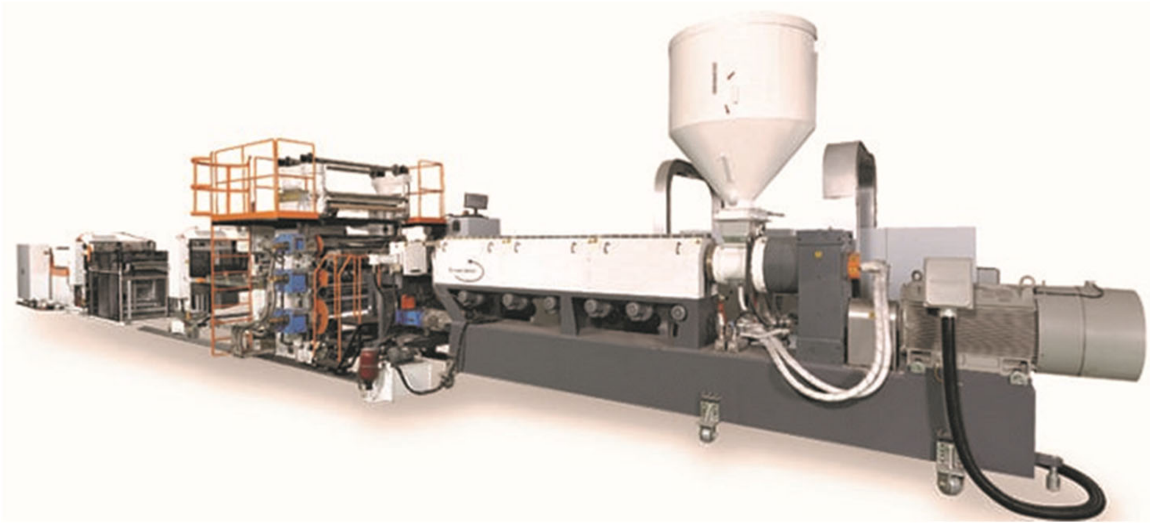

Figure 3. Full-automatic polypropylene extrusion line (Reprinted with permission from Ref. [32]. Copyright 2022, Sunwell Global).

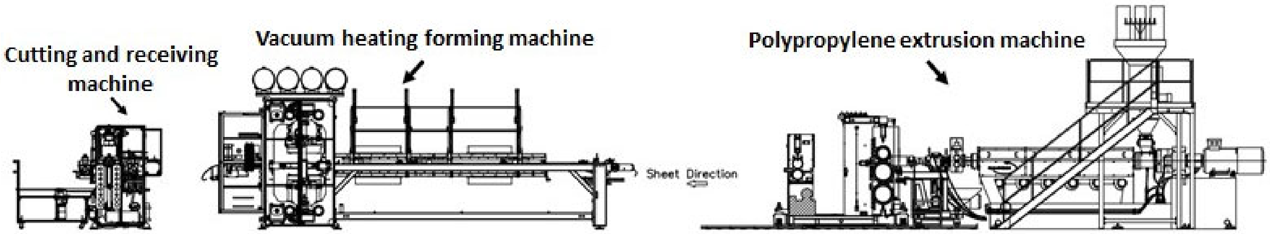

Figure 4. The schematic of polypropylene extrusion and thermoforming in-line system (Reprinted with permission from Ref. [33]. Copyright 2022, Sunwell Global).

2.3. Key Success Factors

Professional quality controllers and production technologists were interviewed using a half-structured method to discuss the key factors in extrusion molding quality [34,35]. The key factor data were judged and collected according to the experience in real production and inspection. The data were scientifically analyzed to determine specific key success factors and obstacles [36]. Four main aspects were induced. The questionnaire content contained 49 subitem key factors, and the key success factors in extrusion molding quality were discussed.

2.4. Delphi Technology

The Delphi technology [37] is used in different areas of academic research [38], including curriculum planning and capability indexing. It can probe into or understand the assumptions and related decisions of many disciplines. If the background knowledge of Delphi technology is used, 10 to 15 experts and scholars for concluding the consensus of Delphi technology can meet the quantity standard of experts and scholars. Through repeated written discussion by anonymous and structured group interviews [39], the scholars and experts establish a consistent consensus with their expertise or technical experience and opinions to solve complex issues [40]. Anonymity is required in the Delphi interview process to avoid the complex factors of interpersonal communication disturbing objective respondence and avoid the psychological factor of authoritarian submission or bandwagon effect induced by leaders or senior executives of the group [41]. The anonymity enables expert group members to express their real opinions further and leads to different levels of considerations. The experts' opinions are fairer. Murry and Hammons [42] indicated that the result of experts' collective discussion and shared decision making should be more comprehensive than the conclusion of individual thinking. The expert group majorly consists of professors and scholars in plastic technique, including two university professors in chemical engineering, 11 scholars in mechanical design in enterprises, and polypropylene product engineers in manufacturing. The Delphi technique group is composed of method analysis scholars including four factory managers and eleven senior engineers with 21 years of experience. The Delphi technique members mainly work in mechanical manufacturing-related or research and development-related plastic extrusion thermoforming processing. These experts were chosen from homogeneous fields of experience and technique with less error and higher reliability.

3. Methodology

The opinions of experts and scholars of Delphi are evaluated according to the five-point Likert scale [43]. The scale represents 5 as very important, 4 as important, 3 as normal, 2 as unimportant, and 1 as very unimportant.

3.1. Research Structure and Method

This study was divided into in-depth interviews with scholars and experts and structured expert questionnaire interviews of the Delphi technique [44]. The selected experts were interviewed with the Delphi questionnaire three times [45]. The key success factors in PP extrusion molding quality were induced by statistical analysis.

3.1.1. Research Methods

The research methods included qualitative and quantitative research [46]. The qualitative research integrated the scholars' and experts' opinions from in-depth interviews through semi-structured interviews. The first Delphi research questionnaire was discussed. The quantitative research selected the structured questionnaire of Delphi for three interviews. A total of four key success factors were developed as the research structure and discussed. After interviews, the experts' opinions were collected to induce the result shown in Figure 5.

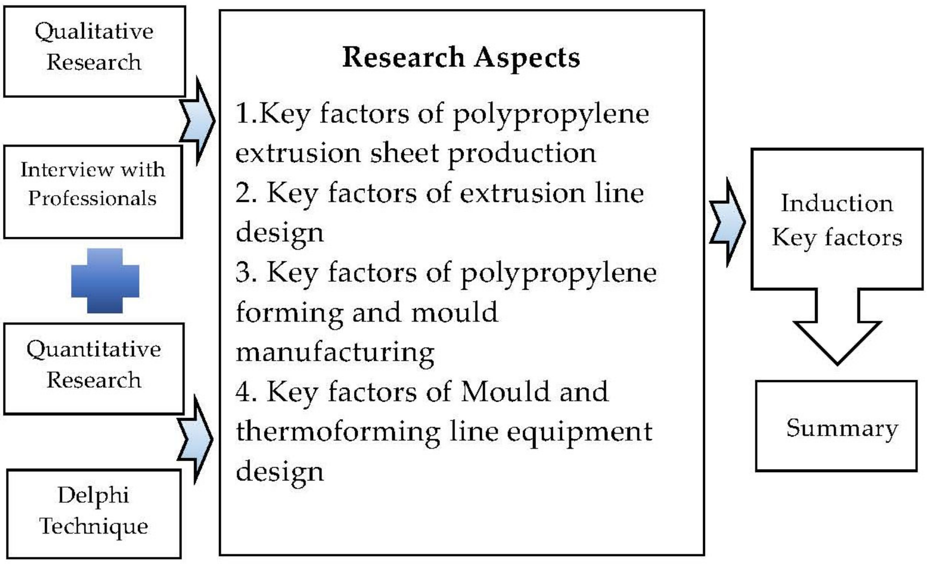

Figure 5. Research structure.

3.1.2. Process of Delphi Technique

The process of three questionnaires of the Delphi technique is shown in Figure 6.

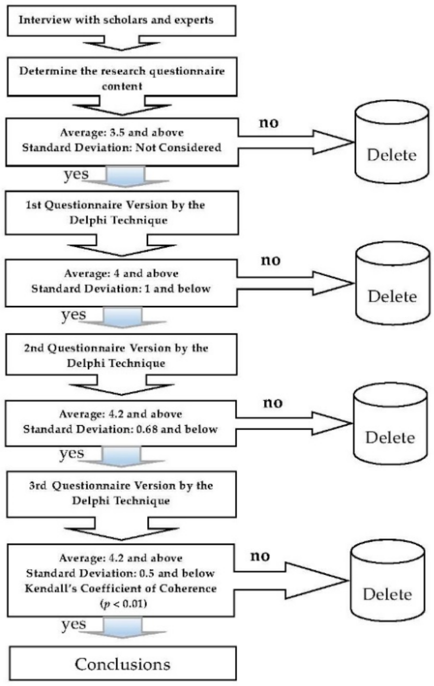

Figure 6. Steps to prepare the questionnaire by the Delphi technique.

3.2. Delphi Research Method and Design

This study established the Delphi questionnaire aspect content. The interview subject team comprised three categories of professionals: (1) scholars of chemical plastic production, (2) senior engineers developing special machines, and (3) technical executives of production manufacturing. Discussions were made according to their expertise, and the Delphi research questionnaire with the four aspects of specific key quality factors and 49 subitems was formulated.

According to the expert interview team's opinion, the Delphi research questionnaire had 13 subitems in dimension 1, "key factors in PP extrusion sheet production technique" [47], as shown in Table 2.

Table 2. Key factors of polypropylene extrusion sheet production (13 subitems).

1-1 The ratio of PP virgin pellets and reclaimed pellets
1-2 PP extruder main screw output pressure control
1-3 PP extruder polymer temperature control
1-4 T-die lips adjustment depends on sheet thickness
1-5 Cooling rolls pressing stability
1-6 Cooling rolls flatness
1-7 Cooling rolls temperature stability
1-8 T-die output and cooling rolls pressing position
1-9 Processing according to extrusion and raw material characteristics
1-10 PP extruder output (experts complement)
1-11 PP sheet thickness (experts complement)
1-12 PP sheet width (experts complement)
1-13 PP extruder main screw geometric design (experts complement)

According to the expert interview team's opinion, there were 12 subitems in dimension 2, "extrusion sheet manufacturing machinery equipment design", of the Delphi research questionnaire [48], as shown in Table 3.

Table 3. Key factors of extrusion line design (12 subitems).

2-1 Extruder main motor coordinate with main screw output
2-2 Gearbox coordinate with main screw output
2-3 Extruder main screw geometric design
2-4 The relationship between the metering pump and main screw output
2-5 The relationship between the metering pump and motor reducer
2-6 Screen changer and main screw diameter output
2-7 The max./min. width of the sheet and die design
2-8 The maximum sheet width and cooling rolls design
2-9 The maximum output of the screw and the cooling design of the cooling rolls
2-10 Cooling rolls and motor reducer design
2-11 Cooling rolls and cooling mechanism strength design
2-12 Maximum sheet width/maximum winding roll diameter and winding mechanism

According to the expert interview team's opinion, there were 12 subitems in dimension 3, "key factors in PP molding [49] and mold manufacturing [50]", of the Delphi research questionnaire, as shown in Table 4.

Table 4. Key factors of polypropylene forming and mold manufacturing (12 subitems).

3-1 Material of vacuum aluminum alloy forming mold
3-2 Requirements for mold vacuum holes and pressure holes
3-3 Feeding stability of forming heater
3-4 Core/cavity and product modeling design
3-5 Forming heating controller element stability
3-6 The deviation of forming heating constant temperature control area
3-7 Near scenic sport or night markets
3-8 Collective residential community, enterprise office building, or factory concentration area
3-9 Mold cooling mode
3-10 Mold clamping to prevent leakage
3-11 Product geometric design
3-12 Product and mold cutter shrinkage

According to the expert interview team's opinion, there were 12 subitems in dimension 4, "mold and molding trimmer equipment design", of the Delphi research questionnaire, as shown in Table 5.

Table 5. Key factors of mold and thermoforming line equipment design (12 subitems).

4-1 Depends on the clamping force of the thermoformer
4-2 The product and mold maximum layout design arrangement
4-3 The maximum forming height of the thermoformer and product mold design
4-4 The maximum trimming width of the trimmer and product mold design
4-5 The maximum clamping force of the thermoformer and mold forming area design
4-6 Thermoformer motor education ratio
4-7 Trimmer motor reducer and trimming mold weight cutting force
4-8 Trimmer platen opening and trimming mold
4-9 Maximum product depth and trimmer opening
4-10 Thermoforming mold and thermoformer platen center positioning clamping
4-11 Trimming mold and trimmer platen center positioning clamping
4-12 Thermoformer cooling pump flowrate

3.3. The Statistical Analysis

For the statistical analysis of the interviews with scholars and experts [51], besides the in-depth interviews with two professor scholars, there were 13 effective questionnaires of interviews with experts of the circle. The statistical results of the first Delphi questionnaire are as follows: (1) the mode was above 4, (2) the high fitness selection criteria were adopted with the mean $\geq$4, and (3) the consistency selection standard deviation was $\leq$1. Forty subitems met the above three requirements, which were kept to establish the second Delphi research questionnaire. According to the statistical result of the second Delphi research questionnaire, the high fitness selection criteria were employed with a mean of $\geq$4.2, and the consistency selection standard deviation was $\leq$0.68. Sixteen subitems meeting the requirements were kept to establish the third Delphi research questionnaire. A statistical analysis of the key subitems of the third questionnaire was conducted via a Kolmogorov–Smirnov one-sample test. The statistical analysis result shows that the expert opinions on each subitem were significant (* $p < 0.05$). This means that the third questionnaire corrected by Delphi was more reliable and valid than the first one. The mean, mode, and standard deviation of the subitems, the Kolmogorov–Smirnov one-sample test, and progressive significance results are shown in Table 6.

Table 6. Statistical analysis of the third Delphi questionnaire.

No.	Item	Mo	M	SD	K–S Z-Test	Choice
1. Key Factors of Polypropylene Extrusion Sheet Production						
1–2	PP extruder main screw output pressure control	5	4.54	0.499	1.941 **	Keep
1–3	PP extruder polymer temperature control	4	4.46	0.499	1.941 **	Keep
1–4	T-die lips adjustment depends on sheet thickness	4	4.38	0.487	2.219 **	Keep
1–5	Cooling rolls pressing stability	4	4.38	0.487	2.219 **	Keep
1–6	Cooling rolls flatness	4	4.23	0.576	1.525 *	Delete
1–7	Cooling rolls temperature stability	4	4.31	0.462	2.496 **	Keep
1–12	PP sheet width (experts complement)	4	4.07	0.615	1.248	Delete

Table 6. *Cont.*

No.	Item	Mo	M	SD	K–S Z-Test	Choice
2. Key Factors of the Extrusion Line Design						
2–3	Extruder main screw geometric design	4	4.23	0.421	2.774 **	Keep
2–4	The relationship between the metering pump and main screw output	4	4.23	0.576	1.525 *	Delete
2–9	The maximum output of the screw and the cooling design of the cooling rolls	4	4.08	0.474	1.525 *	Delete
3. Key Factors of Polypropylene Forming and Mold Manufacturing						
3-4	Core/cavity and product modeling design	4	4.23	0.576	1.525 *	Delete
3-5	Forming heating controller element stability	4	4.46	0.499	1.941 **	Keep
3-6	The deviation of forming heating constant temperature control area	4	4.23	0.421	2.774 **	Keep
3-7	Near to scenic sport or night markets	4	4.46	0.499	1.941 **	Keep
4. Key Factors of Mold and Thermoforming Line Equipment Design						
4-5	The maximum clamping force of the thermoformer and mold forming area design	4	4.23	0.421	2.774 **	Keep
4-9	Maximum product depth and trimmer opening	4	4.15	0.533	1.525 *	Delete

* $p < 0.05$, ** $p < 0.01$.

4. Results

From September 2021 to January 2022, three Delphi structured questionnaire interviews were performed. The statistical results of the third Delphi questionnaire revealed that (1) the high fitness selection criteria was employed with the mean of ≥4.2, (2) the consistency selection standard deviation was ≤0.5, (3) the consensus of the K-S test has reached consistency, and (4) the subitems of progressive significance have reached the significance level of ** $p < 0.01$. The subitems would be kept only when the above four requirements were met. Based on the final statistical analysis result of the third Delphi research questionnaire, the subitems of ten key control factors in production quality were obtained, as shown in Table 7.

Table 7. Statistical analysis of the final Delphi technique.

No.	Item	Mo	M	SD	K–S Z-Test	Choice
1. Key Factors of Polypropylene Extrusion Sheet Production						
1–2	PP extruder main screw output pressure control	5	4.54	0.499	1.941 **	Keep
1–3	PP extruder polymer temperature control	4	4.46	0.499	1.941 **	Keep
1–4	T-die lips adjustment depends on sheet thickness	4	4.38	0.487	2.219 **	Keep
1–5	Cooling rolls pressing stability	4	4.38	0.487	2.219 **	Keep
1–7	Cooling rolls temperature stability	4	4.31	0.462	2.496 **	Keep
2. Key Factors of the Extrusion Line Design						
2–3	Extruder main screw geometric design	4	4.23	0.421	2.774 **	Keep

Table 7. *Cont.*

No.	Item	Mo	M	SD	K–S Z-Test	Choice
3. Key Factors of Polypropylene Forming and Mold Manufacturing						
3-5	Forming heating controller element stability	4	4.46	0.499	1.941 **	Keep
3-6	The deviation of forming heating constant temperature control area	4	4.23	0.421	2.774 **	Keep
3-7	Near to scenic sport or night markets	4	4.46	0.499	1.941 **	Keep
4. Key Factors of Mold and Thermoforming Line Equipment Design						
4-5	The maximum clamping force of the thermoformer and mold forming area design	4	4.23	0.421	2.774 **	Keep

** $p < 0.01$.

4.1. Test Key Factors in Production Quality

The 16 key factors in the third Delphi research questionnaire were analyzed and verified by the Kolmogorov–Smirnov Z test. When the extreme differences and progressive significance (*p*) were analyzed, it was found that the test result matched the progressive significance of the two-tailed $p < 0.01$ test. The analysis result indicated ten key subitems of quality. The key factors for their being retained in the questionnaire were the consensus of scholars and experts who considered these subitems the most critical factors in extrusion molding quality.

4.2. The Delphi Research Analysis Result

According to the Delphi research analysis result, ten key success factor items were induced from the four main aspects of key factors in PP extrusion molding production quality. A fish-bone diagram was used [52] to illustrate these factors in PP extrusion molding production quality, as shown in Figure 7.

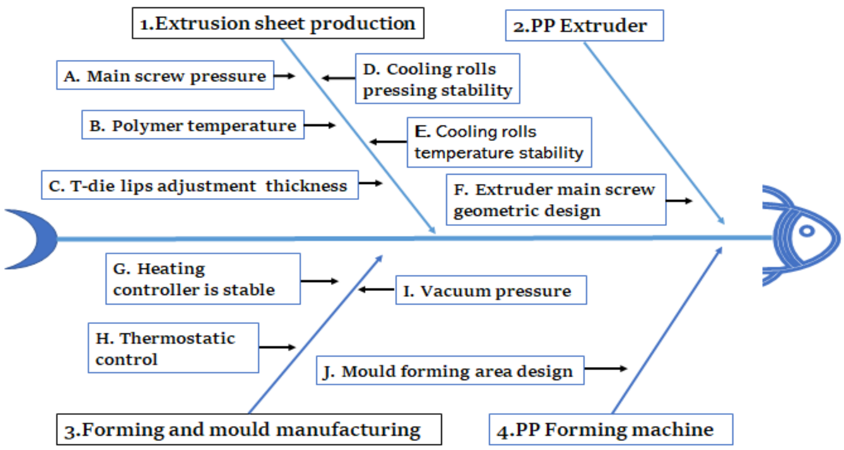

Figure 7. Important key factors affecting the quality of polypropylene extrusion molding.

5. Conclusions

According to the statistical results, the key factors in PP extrusion molding quality control had the following ten key subitems: (1-2) PP extrusion driving screw feed pressure control (correction: PP extrusion driving screw discharge pressure control), abbreviated as A. Main screw pressure; (1-3) PP extrusion resin temperature change control, abbreviated as B. Polymer temperature; (1-4) T-die lips adjustment sheet stability (correction: die lips adjustment depends on sheet thickness), abbreviated as C. T-die lips adjustment thickness; (1-5) mirror wheel pressing stability, abbreviated as D. Cooling rolls pressing stability;

(1-7) mirror wheel temperature stability, abbreviated as E. Cooling rolls temperature stability; (2-3) extrusion driving screw geometric design, abbreviated as F. Extruder main screw geometric design; (3-5) molding heating controller element stability, abbreviated as G. Heating controller is stable; (3-6) molding heating thermostatic control area error value, abbreviated as H. Thermostatic control; (3-7) molding vacuum and compressed air system stability, abbreviated as I. Vacuum pressure; and (4-5) molding machine maximum clamping force and molding area relationship design, abbreviated as J. Mold forming area design. Therefore, the key factors in the PP extrusion molding production quality are abbreviated to "A. Main screw pressure", "B. Polymer temperature", "C. T-die lips adjustment thickness", "D. Cooling rolls pressing stability", "E. Cooling rolls temperature stability", "F. Extruder main screw geometric design", "G. Heating controller is stable", "H. Thermostatic control, "I. Vacuum pressure", and "J. Mold forming area design", totaling ten key control factors in quality. The said key quality factors had a few differences in setting the technical parameters of real production due to different specifications of manufacturing machines and molds. Through the manufacturing and production of S company's intelligent modern extrusion molding machine, with the chain restaurant McDonald's drinks the cup lid as a production case, its production efficiency is more than 1.5 times that of injection molding products, and the production cost is only injection molding. The market price of molded products is about 60%. At present, the innovative and optimized automatic machinery and production technology are not comparable to the general traditional semi-automatic extrusion and cutting molding machines. According to the product weight, the plate thickness is about 0.45 mm~0.65 mm, corresponding to the key control factors of fishbone diagram quality: "A. Main screw pressure control: Speed set at 480~500 rpm", "B. Polymer temperature control at 200~240 °C", "C. T-die lips adjustment thickness is controlled at 0.45~0.69 mm ", "D. Cooling rolls pressing stability pressing control at ±0.05 mm ", "E. Cooling rolls temperature stability is controlled at 20~45 °C", "F. Extruder main screw geometric design adopts American style. Standard", "G. Heating controller is stable controller at 230~250 °C", "H. Thermostatic control error of molding heating ±1 °C", "I. Stability of molding vacuum pressure ±0.01 MPa", "J. Mold forming area design between the mold and the area is designed from 60% to 90% of the size". In the production of food packaging, to reach a good result in production quality control by using isobutane or CO_2 as a blowing agent injected in the extruder to increase the foaming ratio under the physical foaming process can result in less material usage, better isolation purpose, and higher heat resistance, as long as the extruded die and cooling mandrel, etc., are changed. The study can correspond to the key factor in the quality of thermoforming processing. It is confirmed in practical manufacture processing in the experimental factory for an obvious quality and energy-saving improvement. The production processing of the regrind recycling system is assisted in conveying scrapped material from the edge trimmer or crusher back to the extruder loading system in collocating with the automatic volumetric dosing device. The returned recycled material mixes with new material. At the present, the extruder and thermoforming system with precise vacuum forming molds is intelligent automatic machinery. The division of management and procurement are most concerned about having reliable quality and less error. As there are few related literature reviews of the Delphi technique, this study applied science to actual operators engaging in plastic production or clients with plain and specific key factors or data. Worldwide polypropylene sheet production is over 30 million metric tons. The key to the market competition is the condition that the percentage raises up in 1–2% for certified products and regrind recycling material to produce polypropylene coffee cups.

Nonetheless, the findings indicated that the manufacturing quality and energy savings could be improved effectively in the experimental plant. The study findings are expected to improve intelligent manufacturing and quality for production engineers and researchers, enhance the market competitiveness of products, and reduce enterprise management costs. As a result, the findings may contribute to achieving sustainable development, environmental protection, energy savings, and carbon reductions.

Author Contributions: All authors contributed meaningfully to this study. D.-F.C. and S.-M.H., research topic; D.-C.C., S.-M.H. and D.-F.C., data acquisition and analysis; D.-F.C., S.-M.H. and W.-J.S., methodology support; S.-M.H., D.-C.C. and W.-J.S., original draft preparation; D.-F.C. and W.-J.S., writing—review and editing. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Guan, W.J.; Ni, Z.Y.; Hu, Y.; Liang, W.H.; Ou, C.Q.; He, J.X.; Liu, L.; Shan, H.; Lei, C.L.; Hui, D.S. Clinical characteristics of coronavirus disease 2019 in China. *N. Engl. J. Med.* **2020**, *382*, 1708–1720. [CrossRef] [PubMed]
2. da Costa, J.P. The 2019 global pandemic and plastic pollution prevention measures: Playing catch-up. *Sci. Total Environ.* **2021**, *774*, 145806. [CrossRef]
3. Walther, B.A.; Yen, N.; Hu, C.S. Strategies, actions, and policies by Taiwan's ENGOs, media, and government to reduce plastic use and marine plastic pollution. *Mar. Policy* **2021**, *126*, 104391. [CrossRef]
4. Clayton, C.A.B. Building Collective Ownership of Single-Use Plastic Waste in Youth Communities: A Jamaican Case Study. *Soc. Sci.* **2021**, *10*, 412. [CrossRef]
5. Elliott, T.; Gillie, H.; Thomson, A. European Union's plastic strategy and an impact assessment of the proposed directive on tackling single-use plastics items. *Plast. Waste Recycl.* **2020**, 601–633. [CrossRef]
6. Velvizhi, G.; Balakumar, K.; Shetti, N.P.; Ahmad, E.; Pant, K.K.; Aminabhavi, T.M. Integrated biorefinery processes for conversion of lignocellulosic biomass to value added materials: Paving a path towards circular economy. *Bioresour. Technol.* **2022**, *343*, 126151. [CrossRef]
7. Pizarro-Ortega, C.I.; Dioses-Salinas, D.C.; Severini, F.; López, A.F.; Rimondino, G.N.; Benson, N.U.; De-la-Torre, G.E. Degradation of plastics associated with the COVID-19 pandemic. *Mar. Pollut. Bull.* **2022**, *176*, 113474. [CrossRef]
8. Wei, H. Optimisation on Thermoforming of Biodegradable Poly (Lactic Acid), (PLA). *Polymers* **2021**, *13*, 654. [CrossRef]
9. European Commission. *Communication from the Commission, The European Green Deal*; European Commission: Brussels, Belgium, 2019. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1588580774040&uri=CELEX%3A52019DC0640 (accessed on 16 May 2022).
10. Hilton, M.; Sherrington, C.; McCarthy, A.; Börkey, P. *Extended Producer Responsibility (EPR) and the Impact of Online Sales*; OECD Environment Working Papers, No. 142; OECD Publishing: Paris, France, 2019. [CrossRef]
11. Johnson, H.A. Revolutionary Instruments, Lavoisier's Tools, as Objets d' Art. *Chem. Herit.* **2008**, *26*, 30–35.
12. Wu, M.H. Preparation of Maleated and Ionically Modified Polypropylene and Its Application as an Additive for Functional Polypropylene. Ph.D. Thesis, National Cheng Kung University, Taiwan, China, 2020.
13. Maddah, H.A. Polypropylene as a promising plastic a review. *Am. J. Polym. Sci* **2016**, *6*, 1–11.
14. Lau, H.C.; Bhattacharya, S.N.; Field, G.J. Melt strength of polypropylene: Its relevance to thermoforming. *Polym. Eng. Sci.* **1998**, *38*, 1915–1923. [CrossRef]
15. Tripathi, D. *Practical Guide to Polypropylene*; Rapra Technology Limited: Shrewsbury, UK, 2002; pp. 2–82.
16. Ahmedzade, P.; Demirelli, K.; Günay, T.; Biryan, F.; Alqudah, O. Effects of Waste Polypropylene Additive on the Properties of Bituminous Binder. *Procedia Manuf.* **2015**, *2*, 165–170. [CrossRef]
17. Plastics Europe. *Plastics the Facts-2016, an Analysis of European Plastics Production, Demand, and Waste Data*; Plastic Europe: Brussels, Belgium, 2016.
18. Geyer, R.; Jambeck, J.R.; Law, K.L. Production, use, and fate of all plastics ever made. *Sci. Adv.* **2017**, *3*, e1700782. [CrossRef] [PubMed]
19. Brasileiro, L.; Moreno-Navarro, F.; Tauste-Martínez, R.; Matos, J.; del Rubio-Gámez, M.C. Reclaimed Polymers as Asphalt Binder Modifiers, A review. *Sustainability* **2019**, *11*, 646. [CrossRef]
20. Rahman, M.Z.; Hoque, M.E.; Alam, M.R.; Rouf, M.A.; Khan, S.I.; Xu, H.; Ramakrishna, S. Face Masks to Combat Coronavirus (COVID-19)—Processing, Roles, Requirements, Efficacy, Risk and Sustainability. *Polymers* **2022**, *14*, 1296. [CrossRef]
21. China Futures Daily. More than 3000 New Mask and Protective Clothing Companies Are Added, Has the PP Market Felt It? *China Futures Daily*, 11 February 2022.
22. Tammaro, D.; Ballesteros, A.; Walker, C.; Reichelt, N.; Trommsdorff, U. Expanded Beads of High Melt Strength Polypro-pylene Moldable at Low Steam Pressure by Foam Extrusion. *Polymers* **2022**, *14*, 205. [CrossRef]
23. Taiwan Plastics Industry Technology Development Center. *High Melt Strength Polypropylene Materials for Physical Foaming, Plastics Column*; Taiwan Plastics Industry Technology Development Center: Taichung, Taiwan, 2022.

24. Kuhnigk, J.; Standau, T.; Dörr, D.; Brütting, C.; Altstädt, V. Progress in the development of bead foams—A review show less. *J. Cell. Plast.* **2022**, *in press*. [CrossRef]
25. Chen, C.H.; Lin, K.C. The application of new developed expanded polypropylene, Department of Innovative Design and Entrepreneurship Management, Far East University, Tainan, Taiwan, 2013. Available online: https://cheers-longterm-cdn.cwg.tw/upload/1449060140.pdf (accessed on 16 May 2022).
26. George, G. *Thermoforming: A Plastics Processing Guide*; Routledge: London, UK, 2018.
27. Maier, C.; Calafut, T. *Polypropylene: The Definitive User's Guide and Databook*, 1st ed.; Plastics Design Library; Elsevier: Amsterdam, The Netherlands, 1998; pp. 205–221.
28. Eldridge, M. *Mount III Extrusion Processes Applied Plastics Engineering Handbook*; William Andrew Publishing: Norwich, NY, USA, 2017; pp. 217–264.
29. Cantor, K. *Extrusion Overview Blown Film Extrusion*, 2nd ed.; Hanser Publications: Munich, Germany, 2011.
30. Lamont, P.R. Equipment and Processing Considerations for Thin Gauge PP Sheet. *J. Plast. Film. Sheeting* **1998**, *14*, 256–267. [CrossRef]
31. Giles, H.F., Jr.; Mount, E.M., III; Wagner, J.R., Jr. *Extrusion: The Definitive Processing Guide and Handbook*, 1st ed.; Elsevier: Amsterdam, The Netherlands, 2004.
32. Global, S. HIPS/PP/APET Rigid Sheet Extrusion Lines. 2022. Available online: https://www.sunwellglobal.com.tw/tw/product/plastic-sheet-extrusion-lines.html (accessed on 16 May 2022).
33. Global, S. Marketing and Sales. 2002. Available online: https://www.sunwellglobal.com.tw/en/about/marketing-and-sales.html (accessed on 16 May 2022).
34. Gan, Y.; Shen, L.; Chen, J.; Tam, V.W.Y.; Tan, Y.; Illankoon, I.M.C.S. Critical Factors Affecting the Quality of Industrialized Building System Projects in China. *Sustainability* **2017**, *9*, 216. [CrossRef]
35. Long, T.B.; Looijen, A.; Blok, V. Critical success factors for the transition to business models for sustainability in the food and beverage industry in the Netherlands. *J. Clean. Prod.* **2018**, *175*, 82–95. [CrossRef]
36. Abeykoon, C.; McMillan, A.; Nguyen, B.K. Energy efficiency in extrusion-related polymer processing: A review of state of the art and potential efficiency improvements. *Renew. Sustain. Energy Rev.* **2021**, *147*, 111219. [CrossRef]
37. Rowe, G.; Wright, G. The Delphi technique as a forecasting tool: Issues and analysis. *Int. J. Forecast.* **1999**, *15*, 353–375. [CrossRef]
38. Linstone, H.A.; Turoff, M. The Delphi method: Techniques and applications. *Read. Addison-Wesley* **1975**, *29*, 3–12.
39. Jonassen, D.H.; Tessmer, M.; Hannum, W.H. Structured Group Interviews: Delphi Technique. In *Task Analysis Methods for Instructional Design*; Routledge: London, UK, 1998; pp. 275–278.
40. Lima Filho, L.R.; Bastos, J.V.F.; Macêdo-Júnior, R.O.; Silva, L.S.; Santos, B.L.P.; Ruzene, D.S.; Vasconcelos, C.R.; Silva, D.P. Evaluation of the Bibliometric Scenario of the Delphi Method with Brazilian Affiliations. *Int. J. Innov. Educ. Res.* **2020**, *8*, 225–236. [CrossRef]
41. Nworie, J. Using the Delphi technique in educational technology research, Techtrends Link. *Res. Tech. Trends* **2011**, *55*, 24–30. [CrossRef]
42. Murry, J.W., Jr.; Hammons, J.O. Delphi: A Versatile Methodology for Conducting Qualitative Research. *Rev. High. Educ.* **1995**, *18*, 423–436. [CrossRef]
43. Lahiri, K.; Pulungan, Z. Racial/Ethnic Health Disparity in the U.S.: A Decomposition Analysis. *Econometrics* **2021**, *9*, 22. [CrossRef]
44. Ying, L.; Yupin, A.; Liyan, S.; Joko, G.; Dejian, Z. Construction of evaluation indexes of nursing students' quality and safety competencies: A Delphi study in China. *J. Prof. Nurs.* **2021**, *3*, 501–509.
45. Nor, M.Z. Developing a preliminary questionnaire for the faculty development programme needs of medical teachers using Delphi technique. *J. Taibah Univ. Med. Sci.* **2019**, *6*, 495–501. [CrossRef]
46. Chen, D.C.; Chen, D.F.; Huang, S.M.; Huang, M.J.; Shyr, W.J.; Chiou, C.F. Critical Success Factors to Improve the Business Performance of Tea Drink Chains. *Sustainability* **2021**, *13*, 8953. [CrossRef]
47. Tingrui, F.; Barry, H.; Leno, M. Analysis of process parameters related to the single-screw extrusion of recycled polypropylene blends by using design of experiments. *J. Plast. Film. Sheeting* **2017**, *33*, 168–190.
48. Wagner, J.R., Jr.; Spalding, M.A.; Crabtree, S.L. Data Analysis of an Extrusion Experiment. *J. Plast. Film. Sheeting* **2008**, *24*, 137–157. [CrossRef]
49. Kumar, P.S.; Kumar, G.K.; Kommoji, S.; Banerjee, R.; Ghosh, A.K. The effect of material characteristics and mould parameters on the thermoforming of thick polypropylene sheets. *J. Plast. Film. Sheeting* **2014**, *30*, 162–180. [CrossRef]
50. Johansson, K.T.; Reber, D.H. In-Line Extrusion/Thermoforming Techniques for Deep Draw Polyolefin Containers. *J. Plast. Film. Sheeting* **1989**, *5*, 140–153. [CrossRef]
51. Shyr, W.-J.; Shih, F.-Y.; Liau, H.-M.; Liu, P.-W. Constructing and Validating Competence Indicators for Professional Technicians in Fire Safety in Taiwan. *Sustainability* **2021**, *13*, 7058. [CrossRef]
52. Luo, T.; Wu, C.; Duan, L. Fishbone diagram and risk matrix analysis method and its application in safety assessment of natural gas spherical tank. *J. Clean. Prod.* **2018**, *174*, 296–304. [CrossRef]