

Risk and failure aspects in twin screw extrusion

MARKUS MEYER*

Bühler AG, CH-9240 Uzwil, Switzerland

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There is a multitude of norms and general guidelines relevant to machine safety. Two possibilities are discussed which allow a systematic analysis of hazards concerning processes, process steps and machines down to their components, and which allow appropriate measures to be defined. It concerns the so-called FMEA (Fehler-Möglichkeiten- und Einfluss-Analyse = Fault Occurrence and Influence Analysis) and classical safety analysis. Using some examples from the field of extrusion technology, the application of safety analysis is demonstrated and the measures are described that have to be realized to guarantee protection for people.

Keywords: Extrusion, twin screw extruder, food- and feed-extrusion, safety analysis

Introduction

In the global marketplace, international standards are becoming more and more important. Starting in the USA, severe product liability has been established worldwide and has given us unequivocal instructions for the safety of industrial installations. With the continuing developments in technology, process stages, the related machinery and equipment, all reasonable technical measures for the safety of personnel must be realized. In the following, some aspects of safety in extrusion plants are explained, using as an example the development of a new product.

Product liability

Product liability statutes

- *Target of product liability statutes*
Product liability shall clearly be assigned to the supplier and producer. This means that both the producer of a whole machine and the producer of a component can be made liable for any damage caused by reason of a faulty product they supplied.
- *Faulty product*
A product can have been faulty in construc-

tion, manufacture or installation. A product is faulty if it does not provide the safety that reasonably might have been expected after considering all the eventualities.

What occurs in the case of damage?

Any damage can have the following consequences.

- An injured party can claim damages. The injured party, however, has to prove the damage, the fault, and the causal connection between fault and damage. The supplier/producer would then be liable for damages in a case where there is a claim for compensation for damage unless the supplier/producer can prove that he has fulfilled his duty of care in development, production and supply.

How can liability be avoided?

- *Fulfilment of rules*
The manufacturer is committed
 - to fulfil all relevant EC guidelines during development and planning of products,
 - to document the efforts concerning safety of the product,
 - to document the manufacturing processes and tests, and
 - to provide the correct presentation of his products (advertising media, operating instructions).

*E-mail: es.buhler@buhlergroup.com

- **Safety analysis**
The manufacturer is committed to perform an analysis to determine all the hazards which might be caused by his machine. The results of the hazard analysis and the measures to eliminate the recognized danger in order to save persons are to be listed in the technical documentation. If it is absolutely impossible to eliminate them, he must provide prior warning.
- **Safety standard**
The safety requirements have to be realized by solutions that satisfy the present state of technology.

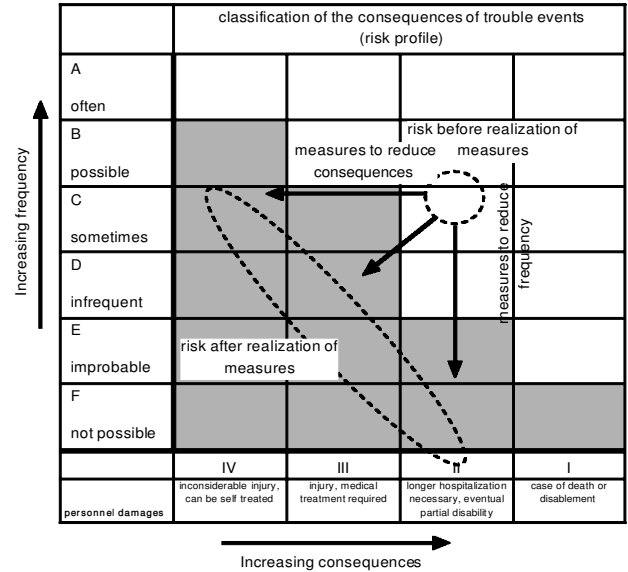


Figure 1 Risk diagram

Instruments to guarantee product safety

There are two methods for analysing the security of industrial installations.

- **FMEA** (Fehler-Möglichkeiten- und Einfluss-Analyse). FMEA is a method for identifying at an early stage any possible faults during the development of a new product and eliminating them by appropriate actions. FMEA is often applied to seek possible faults which may lead to damage in operation. This serves to maximize product quality. For this procedure personal security is not the most important thing. As a first step the construction and operation are scanned for potential faults (type of fault, cause and consequences). The possible fault is then weighted by the product of the probability of occurrence \times consequences \times probability of discovering it. A priorities catalogue is created from this and used to determine which of the problems have to be solved urgently, which are of medium significance, and which require no action. After taking account of all the faults, the improved status is then reanalysed.
- **Safety analysis**. This serves to examine facilities and machines principally with regard to personal protection. The risk R is defined as event probability $P \times$ consequence T . The results of the analysis are shown in a risk diagram (Fig. 1). By appropriate actions all risks situated in the right upper section of the matrix are moved to the left lower section. Appropriate actions aim to minimize the risk by reducing the frequency and/or the consequences.

The process step extrusion

Figure 2 shows the process step extrusion, consisting of a pre-conditioner and a extruder, while Fig. 3 illustrates the flow of material. The parts in detail are:

- Pre-conditioner (1) with paddle shafts
- Drive with motor (2), gear box (4), coupling (3), base frame (5)
- Section of screw-shaft coupling (6)
- Extruder inlet (7)
- Process section with inlet barrel (8), process barrel (9), degassing barrel (10), process shaft (11)
- Degassing spout (12)
- Temperature control channel (13) and cable channel (14)
- Extrusion head with die (15)
- Cutter (16)
- Operating panel (17)
- Terminal box/power panel

The natural appearance of the main parts, only schematically illustrated in Figs 2 and 3, is shown in Figs 4 and 5. Having identified the individual zones of the installation, the next step is to determine the danger zones.

Danger zones

The principal danger zones of the process steps of pre-conditioning and extruding are:

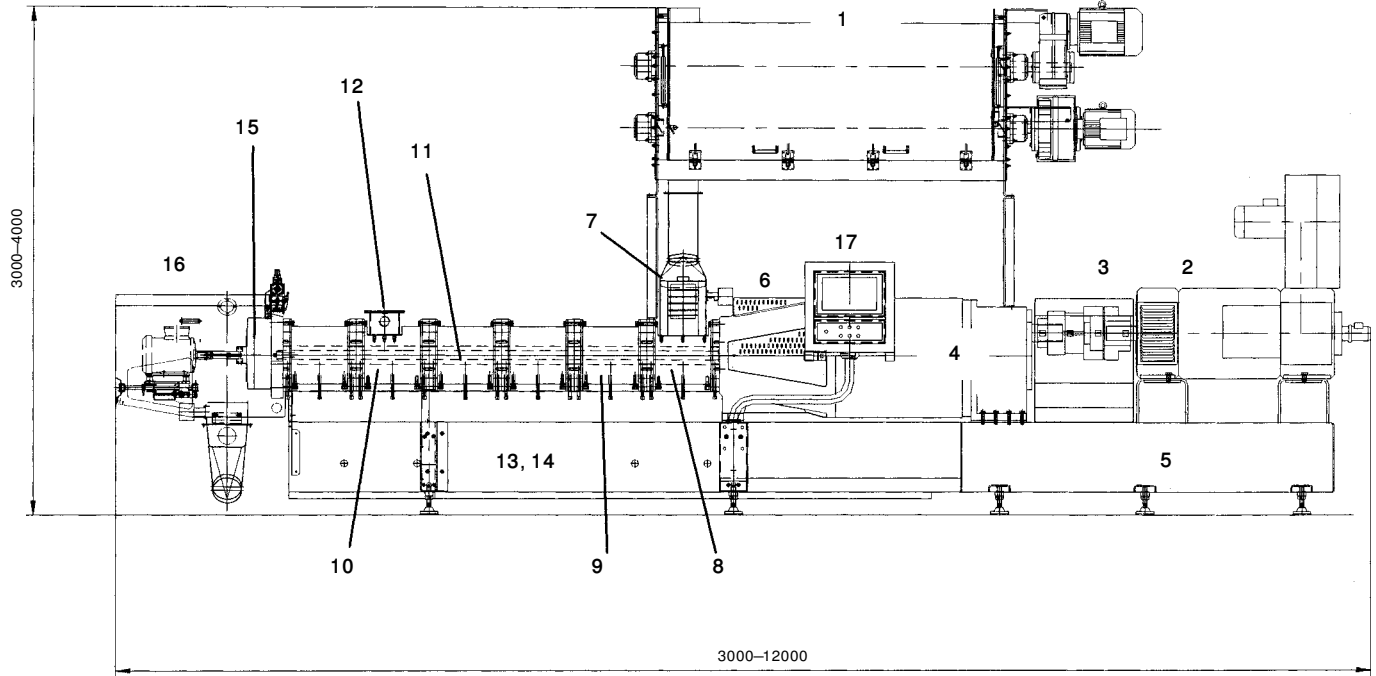


Figure 2 Process step preconditioner/extruder. See text for details.

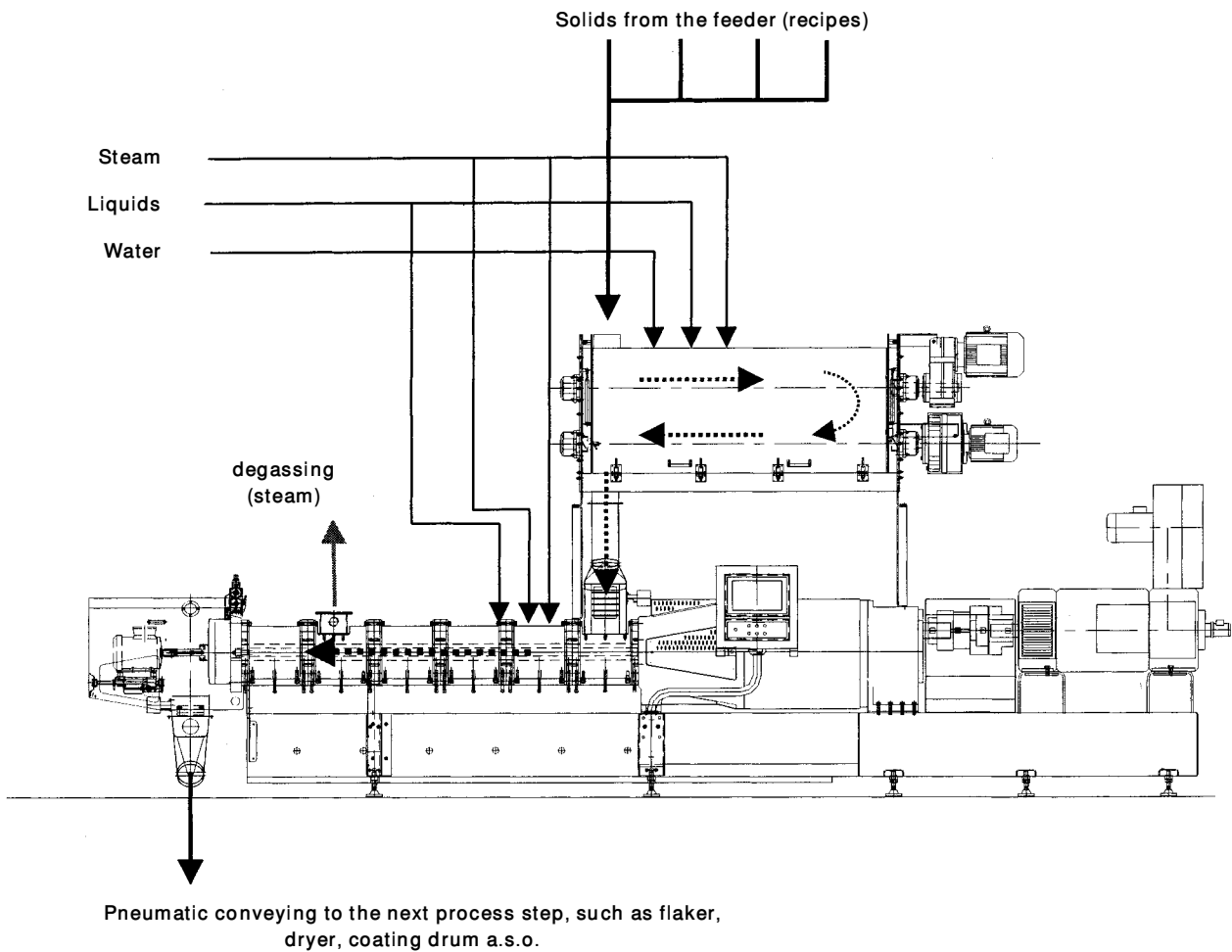


Figure 3 Material flow when solid, steam, water and liquid are added

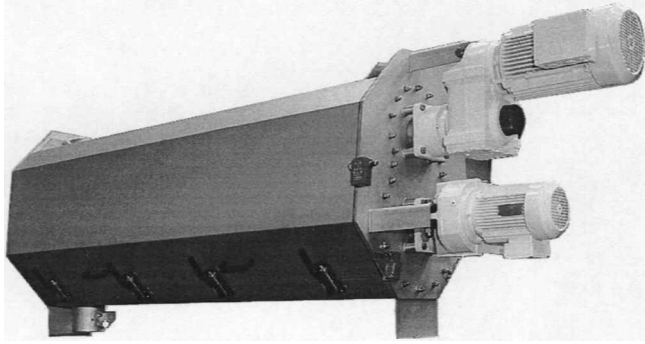


Figure 4 Preconditioner with mixing and retention zone for continuous mixing, heating up and pre-cooking of flour batches in food and feed applications

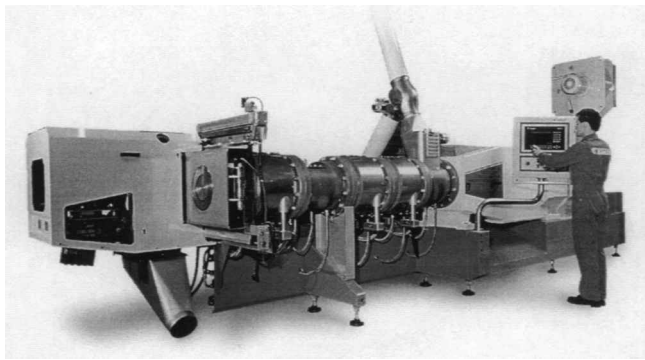


Figure 5 Extruder for continuous mixing, kneading, gelatinizing and forming of flour batches to produce snacks, cereals, functional foods, ingredients, pet foods, aqua-feed, etc.

1. pre-conditioner with paddle shafts and hot surfaces
2. main motor with transfer of force on the gearing
3. gear box with transfer of force on the screw shafts
4. extruder inlet
5. barrel heating system with hot surfaces
6. degassing
7. extrusion head
8. cutter
9. terminal box/power panel

After these danger zones have been listed and considered, the extruder system can be examined according to the Safety Analysis documented below. Under this Safety Analysis, only those risks are considered where personal injury may result. However, the analysis is incomplete in that, for example, the pre-conditioner part is not included.

Safety analysis

When analysing the safety of a product or a process the first step is to establish a risk catalogue as presented in Table 1. Next a catalogue of measures for overcoming these risks must be established, as shown in Table 2. This procedure finally will lead to a revised risk diagram as shown in Fig. 6.

Symbols used

T: Consequences

I = very large
(catastrophic)
II = large (critical)

III = medium

IV = small (insignificant)

H: Frequency

A = often
B = possible
C = sometimes
D = infrequent
E = improbable
F = not possible

case of death or disablement
longer hospitalization necessary, eventual partial disability
injury, medical treatment required
light injury, can be self-treated

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This article is not meant to be final and/or complete. It may not be used as reference.

Conclusion

Through diligent safety analysis, most disruption of production, including damage to property and/or injury to personnel can be avoided. However, a presupposition is that all the danger has been recognized. Across the range of potential personal injury they mostly are evident. However, faulty construction that could lead to damage to property is more difficult to assess (and inevitably Murphy's law applies). Therefore it is essential to set up an expert team to apply this method and to reapply it throughout the various stages of machine development.

Table 1 Risk catalogue

No.	Hazard	Cause	Consequence	T	H
Cutter					
1	Rotating blades	Manipulation mistake (grabbing into)	Cut injury	II	C
2	Ejecting blades	Broken blades	Cut injury	II	C
3	Pneumatic closing	Manipulation mistake	Contusion	III	C
4	Pneumatic opening	Manipulation mistake	Contusion	III	C
6	Access to the blades from the top side	Missing cover	Cut injury	II	C
7	Access to the blades from the top side	Blade adjustment, maintenance work	Cut injury	II	C
8	Access to the blades from the underside	Manipulation mistake, sampling	Cut injury	II	C
9	Pneumatic opening	Process interlock	Scalding from shoot out of product	I	B
10	Shaft of cutter motor	Manipulation mistake	Body injury	III	C
11	Cutter motor	Short circuit, splashing water	Electrical shock	III	C
Extruder inlet/degassing spout					
24	Grabbing into the extruder inlet	Missing cover	Cut injury	II	C
25	Sight glass at the degassing spout	Cracking of sight glass due to over pressure	Body injury, scalding	II	D
Drive					
26	Noise	Too high emission sound pressure level	Hearing damage	III	A
37	Coupling motor-gear box	Manipulation mistake, missing cover	Injury by hit, contusion	II	C
38	Coupling gear box-screw shafts	Manipulation mistake, missing cover	Injury by hit, contusion	II	C
40	Failure of coupling motor-gear box, unbalance	Ejecting parts	Body injury	II	D
43	Main motor	Short circuit, splashing water	Electrical shock	II	D
Process section/extrusion head					
13	Extrusion head opened	Manipulation mistake, maintenance work	Scalding, body injury	III	C
28	Leakage of heat transfer oil to the outside	Leakage of barrels/screw connections	Scalding	II	D
29	Leakage of steam	Leakage of barrels/screw connections	Scalding	II	D
30	Pipes with hot oil, hot water, steam	Contact with hot pipes	Scalding	III	B
31	Electrical barrel heating	Contact with hot surface	Scalding	III	D
32	Electrical barrel heating	Splashing water	Electrical shock	II	D
36	Over pressure in the barrels	Process conditions	Body injury	II	D

Table 2 Catalogue of measures

No.	T	H	Hazard	Measures
Cutter				
1	II	E	Rotating blades	Electrical interlocking, safety category 3 (EN 954), mech. retarding element for blade stop
2	IV	C	Ejecting blades	Closed housing
3	IV	C	Pneumatic closing	Movement controlled through pulse push-button, automatic re-opening at premature releasing
4	III	E	Pneumatic opening	Floor marking or fixed guard by civil engineering, note in operation manual
6	II	E	Access to the blades from the top side	Screen cover fixed with bolts, note in operation manual
7	II	E	Access to the blades from the top side	Screen cover fixed with bolts, note in operation manual
8	II	E	Access to the knives from the under side	Design of outlet spout: ratio of sample hole diameter/distance to blades according to EN 294
9	IV	B	Pneumatic opening	Solid cover, fixed with bolts, note in operation manual + warning sign on the machine + floor marking
10	III	E	Shaft of cutter motor	Cover
11	III	E	Cutter motor	IP55
Extruder inlet/degassing spout				
24	II	E	Grabbing into the extruder inlet	Prevention of access according to EN 294
25	II	E	Sight glass at degassing spout	Splinter resistant sight glass, fixed with elastic force, note in operation manual, standard lid/flange (may not be exchanged)
Drive				
26	III	D	Noise	Noise values noted in the operation manual, protocols of the sound pressure level measurements
38	II	E	Coupling motor-gear box	Solid cover, fixed with bolts
39	IV	E	Coupling gear box-screw shafts	Adjusted and interlocked by the manufacturer
40	IV	E	Failure of coupling motor-gear box, unbalance	Solid cover, fixed with bolts; note in the operation manual
43	II	E	Main motor	IP55, IC37, cleaning only with equipment turned off, note in the operation manual, local switch
Process section/extrusion head				
13	IV	D	Extrusion head opened	Note in the operation manual, personal protection kit (safety gloves), local switch for the main motor
28	II	E	Leakage of heat transfer oil to the outside	Leak test of barrels and of plugs before assembling (definition of test pressure)
29	II	E	Leakage of steam	Leak test of plugs before assembling (definition of test pressure)
30	III	E	Pipes with hot oil, hot water, steam	Leak test of plugs before assembling (definition of test pressure)
31	III	E	Electrical barrel heating	Note in the operation manual, warning sign on the machine
32	II	E	Electrical barrel heating	IP65
36	II	E	Over pressure in the barrels	Appropriate construction, pressure sensor before the die, note in the operation manual

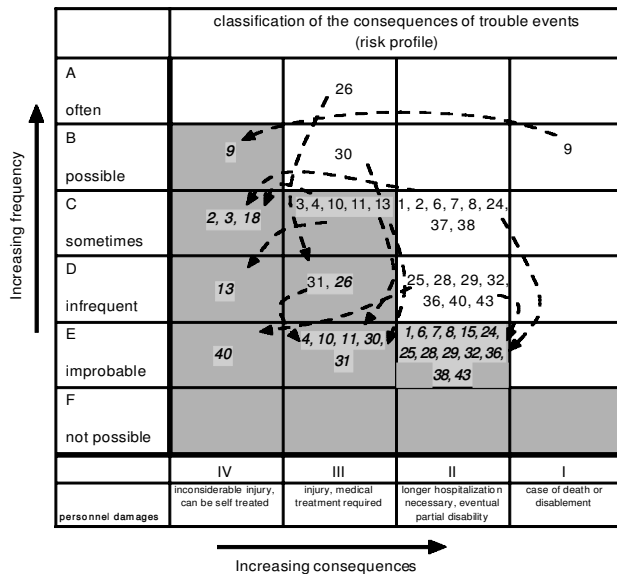


Figure 6 Revised risk diagram. See Tables 1 and 2 for details.

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