Hazard Analysis for the Manufacture of a UN Gas Generant

Kazuo Hara*, Mitsuhiro Kanazawa*, N.Forster** and Tadao Yoshida*

* Department of Materials Chemistry, Hosei University
3-7-2 Kajino-cho, Koganei-shi, Tokyo 184, Japan

** Department of Chemistry, Lehigh University
6 East Paiken Avenue, Bethlehem, PA 18015-3172, USA

ABSTRACT

The Yoshida Hazard Analysis (YHA) was applied to the manufacturing of a gas generant composed of Urazole, a metal nitrate (Urazole/ MNO_3) and other materials. The safety hazards of the materials used in the manufacturing process were identified and evaluated in a hazard catalog, and the risks of each unit operation in the process were plotted on risk profiles for normal operations, operations which deviated from normal, and corrected operations. In the course of making these risk profiles, the hazards of operations that deviate from the normal were identified and measures for safe operations and handling of materials were instituted.

Keywords: hazard analysis, gas generant, risk profile, urazole, airbag

1. Introduction

Originally, the AK (Azodicarbonamide [ADCA]/$KClO_4$) gas generant for automotive airbag inflators was developed by the author's group to replace the azide-based gas generant.[1] The so-called UN (i.e., Urazole/MNO_3) gas generant was then developed as an improved system. The UN gas generant is more stable and has a lower combustion temperature than the AK gas generant. The qualities of stability and lower combustion temperature are advantageous for the safety and performance of gas generants. In developing the new gas generant system, the fire and explosion hazards of the composition, as well as, of the raw materials were evaluated. It has been confirmed that the Urazole and the UN composition are safer than the ADCA and AK composition.[2]

Herein we describe the results of the hazard analysis for the manufacturing process for the new gas generant. This has been done using the experimental results from hazard evaluations. The YHA technique AK gas generant,[3] the Process Safety Management (PSM) of the Occupational Safety and Health Administration (OSHA),[4] the Zurich Hazard Analysis (ZHA) of the Zurich Insurance Company[5] and the United States Military Standard[6] were referred to in developing the YHA.

2. Yoshida Hazard Analysis for Energetic Materials (YHA)

2.1 Outline of the YHA

The YHA is a method for preventing accidents caused by energetic materials during their manufacturing and handling. The YHA consists of a risk evaluation which uses experimental data on energetic materials and three risk profiles: one for normal operations, one for operations deviating from normal, and one for corrected operations. For these purposes, risk is defined as follows:

Risk = (probability of occurrence) ×
(severity of damage)

The following items are evaluated in the YHA:

1) The scope of the project
2) Diagrams of the process, the flow of materials and the equipment

3) Material safety information
4) Process technology information
5) Hazard identification and risk catalog
6) Risk profiles
7) Safety measures
8) Prevention of deviation from normal operation and corrected risk profiles
9) Conclusions

2.2 Probability of the Occurrence of Fire and Explosion

It is assumed that the probability of occurrence of fire and explosion is a function of the sensitivity and mode of handling of hazardous materials including pyrotechnic compositions, intermediates and raw materials. Expressed symbolically,

$$P = f(S,H)$$

where P is the probability of occurrence of fire and explosion, S is the sensitivity of the materials, and H is the mode of handling of materials. The sensitivity of materials is divided into four categories corresponding to the probability of the occurrence of an event:

Level	Probability	Sensitivity
A	Frequent	High
B	Occasional	Medium
C	Remote	Low
D	Impossible	None

2.3 Criteria of Sensitivity

A high-sensitive material may be ignited frequently during ordinary handling. A medium-sensitive material requires a strong stimulus to be ignited. A low-sensitivity material will not be ignited nor initiated without very high friction, high impact, shock, electric spark, contact with a hot object or high temperature. After many experiments,[2,7–14] criteria for sensitivities have been determined for explosives, propellants and pyrotechnic compositions (Tables 1–5).

2.4 Effect of an Event: Degree of Damage

The degree of damage caused by fires or explosions of hazardous materials is assumed to be a function of the violence of the fire or explosion, the amount of material involved and environmental conditions. Symbolically,

$$D = g(V,M,E)$$

Table 1. Criteria for Impact and Shock Sensitivity.

Level	Sensitivity	Test	Criterion	Ref.
A	High	Drop Ball (Direct Impact)	$E_{50} \le 1.0$ J	7
		Shock Ignitability (No. 0 Det.)	$I_{50} \ge 5$ mm	8
B	Medium	Shock Ignitability (No. 0 Det.)	$I_{50} < 5$ mm	8
		VP30 PVC Tube (No. 6 Det.)	Propagation	10
C	Low	VP30 PVC Tube (No. 6 Det.)	No Propagation	10
		UN Gap (160 g Booster)	Propagation	11
D	No	UN Gap (160 g Booster)	No Propagation	11

Table 2. Criteria for Friction Sensitivity.

Level	Sensitivity	Test	Criterion	Ref.
A	High	BAM Friction	$M_{50} \le 1$ kg	12, 14
B	Medium	BAM Friction	1 kg $< M_{50} \le 10$ kg	12, 14
C	Low	BAM Friction	10 kg $< M_{50} < 36$ kg	12, 14
D	None	BAM Friction	36 kg $< M_{50}$	12, 14

Table 3. Criteria for Electric Spark Sensitivity.

Level	Sensitivity	Test	Criterion	Ref.
A	High	For High-Sensitivity	$E_{50} \leq 1.0$ J	13, 15
B	Medium	For High-Sensitivity For Medium-Sensitivity	1.0 J < E_{50} E_{50} < 10 J	13, 15 13, 15
C	Low	For Medium-Sensitivity	10 J < E_{50} E_{50} < 100 J	13, 15 13, 15
D	None	For Medium-Sensitivity	100 J < E_{50}	13, 15

Table 4. Criteria for Ignition by Contact with Hot Objects.

Level	Sensitivity	Test	Criterion	Ref.
A	High	Cerium–Iron Spark	Ignition	14
B	Medium	Cerium–Iron Spark Conical pile (Ni–Cr)	No Ignition Ignition	14 2
C	Low	Conical pile (Ni–Cr) VP30 PVC Tube (5 g Ignitor)	No Ignition Ignition	2 2
D	None	VP30 PVC Tube (5 g Ignitor)	No Ignition	2

Table 5. Criteria for Thermal Stability (Tentative).

Level	Sensitivity	Test*	Criterion**
A	High	SC—DSC	T_{DSC} < 100 ºC
B	Medium	SC—DSC	100 ºC < T_{DSC} < 200 ºC
C	Low	SC—DSC	200 ºC < T_{DSC}
D	None	SC—DSC	No Exotherm

* SC = Sealed Cell
DSC = Differential Scanning Calorimetry
** T_{DSC} = DSC onset Temperature

where D is the degree of damage; V, the violence of the event; M, the amount of hazardous materials involved; and E, the environmental conditions.

To assign materials to hazard ranks according to the violence of the fire or explosion and the amount of materials involved, materials are classified as follows:

1) Primary explosives, which show a deflagration to detonation transition upon ignition.
2) Semi-primary explosives, which show a deflagration to detonation transition under some conditions after ignition.
3) Detonating explosives, which explode after initiation with a No. 6 detonator.
4) Deflagrating explosives, which burn with high speed without a shock wave when ignited or initiated by shock, or which detonate by strong initiation under tight confinement.
5) Combustible materials, which burn with low speed after ignition.
6) Poorly-combustible materials, which burn only when an external fire is involved.
7) Non-combustible materials.

The range of quantities of materials corresponding to the classification and damage ranking is listed in Table 6. The effect of environmental conditions will be taken into considera-

Table 6. Damage Ranks, Degree of Damage and Ranges of Amounts (m) of Materials.

Rank	Damage	Range of Inventory: Primary Explosives	Range of Inventory: Semi-Primary Explosives	Range of Inventory: Detonating Explosives
I	Catastrophic	100 g ≤ m	1.0 kg ≤ m	10 kg ≤ m
II	Critical	10 g ≤ m < 100 g	100 g ≤ m <1.0 kg	1.0 kg ≤ m < 10 kg
III	Marginal	1.0 g ≤ m <10 g	10 g ≤ m < 100 g	100 g ≤ m < 1.0 kg
IV	Negligible	m < 1.0 g	m < 10 g	m < 100 g

Rank	Range of Inventory: Deflagrating Explosives	Range of Inventory: Combustible Materials	Range of Inventory: Poorly-Combustible Materials	Range of Inventory: Non-Combustible Materials
I	100 kg ≤ m	m = ∞	m = ∞	m = ∞
II	10 kg ≤ m < 100 kg	1.0 t ≤ m	m = ∞	m = ∞
III	1.0 kg ≤ m < 10 kg	100 kg ≤ m <1.0 t	m = ∞	m = ∞
IV	m < 1.0 kg	m ≤ 100 kg	m = ∞	m = ∞

tion when the YHA is applied to an actual process.

2.5 Risk Profile and Acceptable Levels

The risk profile and acceptable levels are shown in Figure 1. In this case, two acceptable levels are defined. One is acceptable without review; the second is acceptable under some restrictions with strict reviewing.

In the YHA, three risk profiles are used. The first is an expected or preliminary profile made with the assumption that process operates normally. The second is made by assuming the

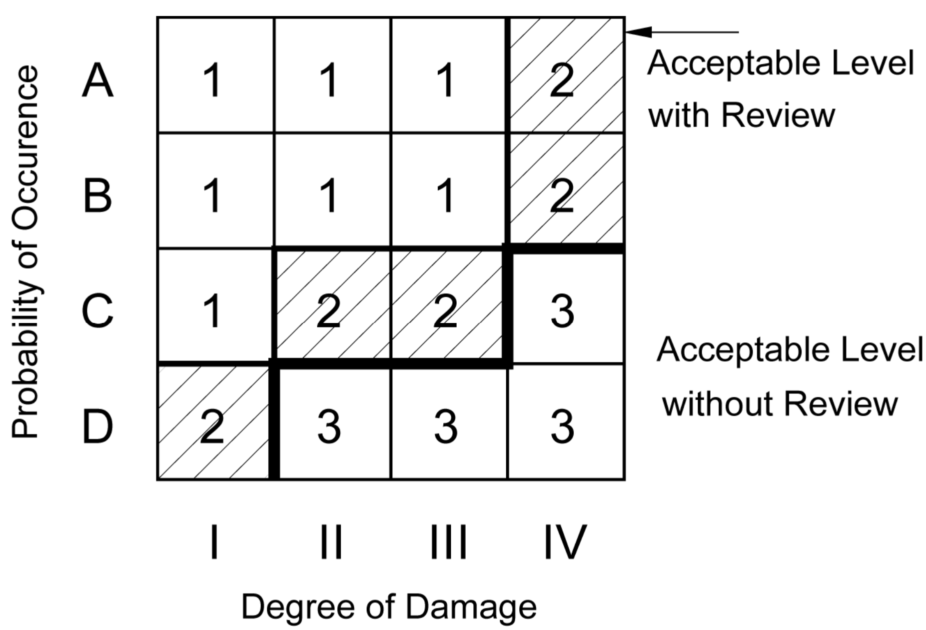


Figure 1. Risk profile and acceptable levels.

worst case of deviation from normal operation. After the second profile is made, safety measures are examined. Finally, a corrected risk profile is made and measures for preventing hazardous deviations from normal operations are shown. This assessment is especially useful for preventing human error.

3. Diagrams of Process and Material Flow and the Equipment

3.1 Flow Diagram of Processes

The flow diagram of the process for the manufacture of a UN gas generant is shown in Figure 2. In mixing raw materials, additive 1 and potassium nitrate (KNO_3) or additive 2 (another oxidizer) should not be mixed directly. If additive 1 is mixed directly with these materials, the resultant combination is highly sensitive and burns violently.

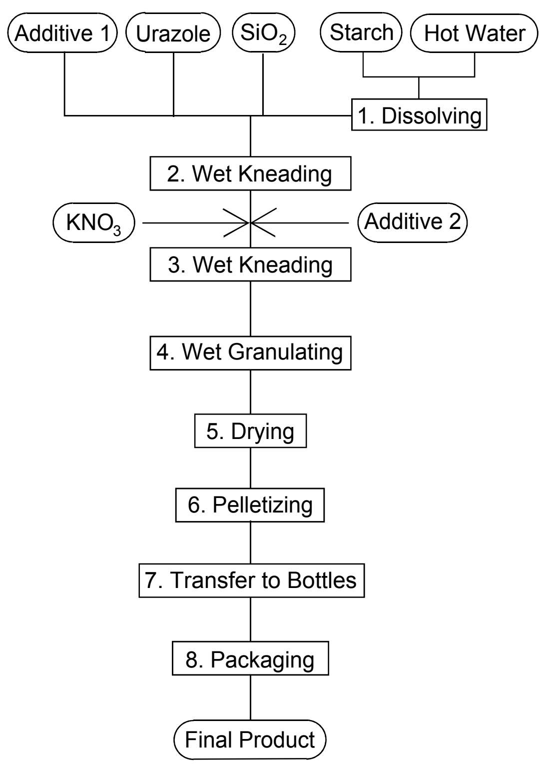


Figure 2. Flow diagram for manufacturing UN gas generant.

3.2 Flow Diagram for Materials

The flow diagram for materials used in the process is shown in Figure 3. The raw materials are Urazole, KNO_3, silicon dioxide (SiO_2), soluble starch, water, additive 1 and additive 2. Additive 1 and additive 2 are classified as fuel and oxidizer, respectively. The intermediates are the dry mixture of Urazole, SiO_2, soluble starch and additive 1, the wet mixture (2) of all raw materials, the wet granules of mixture (2), the dried granules, the dry pellets in bulk, and the dry pellets in bottles. The final products are the packages containing the pellets in bottles.

3.3 Equipment

The primary equipment used in the manufacturing process are a dissolving vessel, a kneading mixer, a granulator, drying ovens and a tabletting machine. The dissolving vessel for the soluble starch has a capacity of approximately 20 liters. It is made of stainless steel and is heated by steam. The mixer is a kneading mixer. The dry Urazole, SiO_2 and additive 1 are fed into the

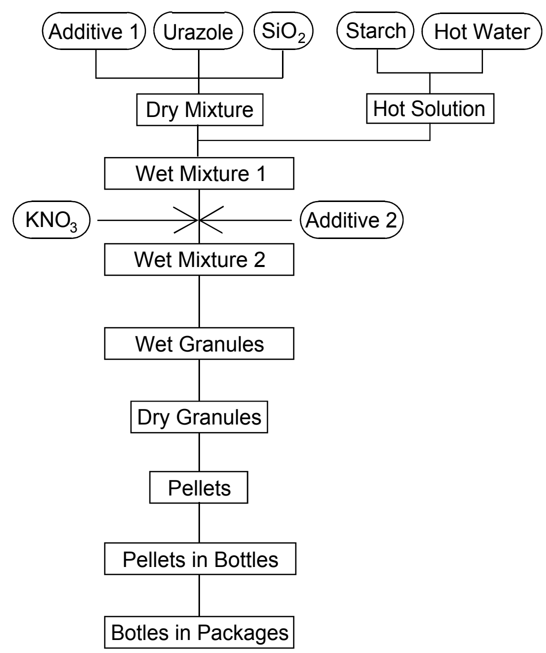


Figure 3. Materials flow diagram for manufacturing UN gas generant.

mixer and are preliminary mixed. The starch solution is added and mixed. KNO_3 and additives are added to the mixture, which is then kneaded thoroughly. The granulator is a screw extruder. The composition in the granulator is wet with water and therefore safe.

The drying oven is a warm air circulating oven equipped with a safety device to prevent overheating. The drying operation is the most hazardous among all the unit operations because the possibility exists that dry granules in bulk will ignite in the oven. The tabletting machine is a rotary type. Friction is high between the pestle and mortar during the tabletting operation, and the decomposition of AK in the machine has been observed. However, the decomposition in the mortar did not affect the outside of the mortar.

4. Material Safety Information

4.1 Sensitivity of Materials

The sensitivity determinations were carried out,[2] and the sensitivity criteria based on this as well as previous work[3] are listed in Tables 1–5. The sensitivity levels of the raw materials, intermediates and products of the UN gas generant are listed in Table 7.

The thermal stability level of UN is ranked "C" because the exothermic onset temperature, T_{DSC} = 260 ºC. If the material is involved in fire or is contacted by a hot object over 200 ºC in temperature for long periods, the material may become hazardous. However, all raw materials used in this process are safe at room temperature.

Insufficient control of the oven's temperature and deficiencies in cleaning the drying oven in addition to changing the composition of the mixture without assessing the stability of new ingredients may contribute to an accident. The pellets described present no problem if they are handled normally.

Table 7. Sensitivity Levels of Materials Used in the Process.

No.	Materials	Impact Shock	Friction	Electric Spark	Hot Objects	Thermal Stability	Note
1	Urazole	D	D	D	D	C	Raw Material
2	KNO_3	D	D	D	D	D	Raw Material
3	SiO_2	D	D	D	D	D	Raw Material
4	Starch	D	D	D	D	D	Raw Material
5	Hot H_2O	D	D	D	D	D	Raw Material
6	Additive 1	D	D	D	D	D	Raw Material
7	Additive 2	D	D	D	D	D	Raw Material
8	Hot Soln.	D	D	D	D	D	Intermediate
9	Dry Mix.	D	D	D	D	C	Intermediate
10	Wet Mix. 1	D	D	D	D	D	Intermediate
11	Wet Mix. 2	D	D	D	D	D	Intermediate
12	Wet Gran.	D	—	D	D	D	Intermediate
13	Dry Gran.	D	—	D	C	C	Intermediate
14	Pellets	D	—	D	C	C	Product
15	Pellets in Bottles	D	—	—	C	C	Product
16	Bottles in Packages	D	—	—	C	C	Final Product

4.2 Combustion Categories, Amounts and Damage Levels of Materials in the Manufacturing Process

The combustible or explosive materials used in the process are:

Poorly-combustible Materials: Urazole, soluble starch, dry and wet mixture of Urazole, SiO_2 and additive 1, wet mixtures of all raw materials and wet granules;

Combustible Materials: dry granules, pellets in bulk, pellets in bottles and bottles in packages.

The risk of dry pellets, pellets in bulk and pellets in bottles must be evaluated. An inventory amount corresponding to one batch from the process is assumed to consist of less than 100 kg at the stage of mixing and less than 20 kg in the drying operation. The combustibility categories, inventory amounts and damage levels for materials in the process are listed in Table 8.

4.3 Effect of Materials on Health and the Environment

Information on the effect of materials used in the process on the health of people in the work place and on the environment was collected. The 50% lethal does (LD_{50}) and the time weighed average–threshold limit value (TLV–TWA) are listed in Table 9. The inhalation toxicity of SiO_2 depends on its particle type, so use of the least toxic form of SiO_2 is recommended.

5. Process Technology Information

The process information is described according to the OSHA standard[4] as follows:

5.1 Flow Diagram for Process

This was presented in Figure 2.

Table 8. Combustibility Categories, Inventory Amounts and Damage Levels of Materials in the Process.

No.	Materials	Combustion Category	Max Batch Inventory	Damage Level
1	Urazole	Poor-Combustible	50 kg	IV
2	KNO_3	Non-Combustible	50 kg	IV
3	SiO_2	Non-Combustible	50 kg	IV
4	Starch	Poor-Combustible	10 kg	IV
5	Hot H_2O	Non-Combustible	20 kg	III
6	Additive 1	Combustible	5 kg	IV
7	Additive 2	Non-Combustible	50 kg	IV
8	Hot Soln.	Non-Combustible	20 kg	III
9	Dry Mix.	Poorly-Combustible	100 kg	IV
10	Wet Mix. 1	Poorly-Combustible	100 kg	IV
11	Wet Mix. 2	Poorly-Combustible	100 kg	IV
12	Wet Gran.	Poorly-Combustible	100 kg	IV
13	Dry Gran.	Combustible	20 kg	III
14	Pellets	Combustible	20 kg	III
15	Pellets in Bottles	Combustible	100 kg	IV
16	Bottles in Packages	Combustible	100 kg	IV

Table 9. LD_{50} and TLV–TWA of Raw Materials.

Materials	Toxicity LD_{50} in mg/kg(Animal)	Threshold Limit Values TLV–TWA in mg/m^3 ACGH
Urazole	NA*	NA*
KNO_3	NA*	NA*
SiO_2	3600(Rat)	10
Starch	No	NA*
Water	No	NA*
Additive 1	NA*	NA*
Additive 2	551(Mouse)	NA*

NA* = Not Available.

5.2 Process Chemistry

No chemical reaction takes place during the manufacturing process.

5.3 Maximum Intended Inventory

A maximum intended inventory of 100 kg per batch is expected. In drying operations, a 20 kg batch is assumed.

5.4 Safety Limits of the Operation

(a) Temperature (T)

80 ºC < T < 100 ºC
for dissolving the soluble starch

70 ºC < T < 90 ºC
for drying the granules

0 ºC < T < 40 ºC
for other operations

(b) Pressure

Materials are pressurized in the granulating and tabletting operations. The safety limits for these operations have not yet been set.

(c) Flow Rate

In the granulating and tabletting operations, the flow rates of materials are important factors for considerations of operability as well as hazard. The safety limits for flow rates have not yet been set.

(d) Composition

Changing the composition of the gas generant affects the safety performance of the process. The composition may vary by a maximum of 5% from the normal composition.

5.5 Evaluation of Consequences of Deviations from Normal Operation

(a) Deviations in the Composition

A change in the oxygen balance affects the concentrations of CO and NO_x in the effluent gas. A deviation in the amounts of additive 1 and 2 affects the safety by changing the combustion properties. If the water content of the mixture deviates, the granulating process becomes more difficult to operate.

(b) Deviations in the Operating Conditions

When the operation of the tabletting machine deviates from normal, the toughness and density of the formed pellets changes, and as a result the properties of their combustion are affected.

(c) Deviation in the Amount of Material

Overloading the drying oven causes granules to spill, which may in turn cause accidental ignition. If a large amount of dry granules and pellets is ignited accidentally, the fire is hazardous and may damage individuals and property. If the amount of such materials is limited, any resultant fire can be easily extinguished with a water spray.

(d) Deviation in Pressure

The drying oven should be designed such that pressure does not increase when an accidental fire occurs. The burning speed of a small amount of granules of the UN gas generant is slow under atmospheric pressure, but a large amount burns quickly if under high pressure.

(e) Deviation in Temperature

If the temperature in the drying oven rises too high, dry granules or dust may ignite. If dust is allowed to accumulate on the overheated heater in the oven, it may ignite.

6. Hazard Identification and Risk Catalog

The potential hazards in the manufacturing process for the UN gas generant were identified and ranked by the sensitivity, the combustibility and the amount of material used in the process. Using the results of the hazard identification and ranking, a risk catalog was made for the process as listed in Table 10.

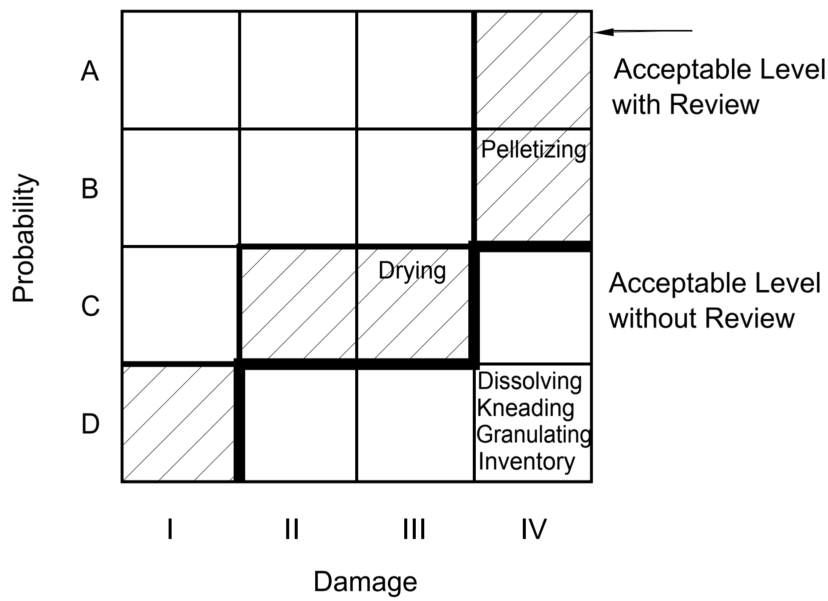
7. Risk Profiles for Normal Operations and Deviations

The risk profiles for normal operations and deviations are shown in Figures 4 (a) and (b), respectively. All operations fall within the acceptable level with review, and only the drying and tabletting operations are outside the acceptable level in the absence of review.

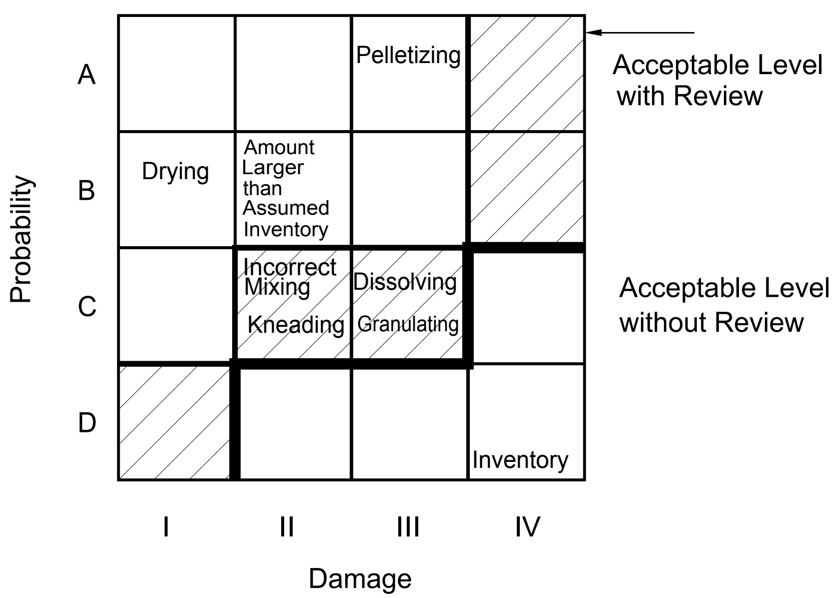
Table 10. Risk Catalog for Operations in the Process.

No.	Operation	Normal	Hazardous Material	Risk Rank	Note
1	Dissolving	Normal	Hot Water	III C	Spill and Scald
		Deviated	Hot Water	IV C	No Problem
2	Wet Kneading	Normal	Wet Mix. 1	IV D	
	No Problem	Deviated	Dry Mix. 1	IV D	Dry Mixing
3	Wet Kneading	Normal	Wet Mix. 2	IV D	
	No Problem	Deviated	Dry Mix. 2	IV C	Dry Mixing
2,3	Dry Mixing	Normal			
		Deviated	Add. 1 + KNO_3	II C	Incorrect Mixing
4	Granulating	Normal	Wet Mix. 2	IV D	No Problem
		Deviated	Dry Mix. 2	III C	Overheating and Ignition
5	Drying	Normal	Dry Gran.	III C	Overheating and Ignition
		Deviated	Dry Gran.	I B	Overheating and Ignition
6	Pelletizing	Normal	Dry Pellets	IV B	Decomp. in Motors
		Deviated	Dry Gran.	III B	Decomp. and Ignition
7	Transfer to	Normal	Pellets	IV D	
	Bottles	Deviated	Pellets	IV D	
8	Packaging	Normal	Pellets	IV D	
		Deviated	Pellets	IV D	
9	Fire	Normal	Gran. and Pellets	III	Normal Amount
		Deviated	Gran. and Pellets	II	Larger Amount than Normal
10	Hot Matter	Normal	Gran. and Pellets	III	Normal Amount
		Deviated	Gran. and Pellets	II	Larger Amount than Normal

Many case histories are known involving hazards in the drying operations of energetic materials. Although the UN composition is stable, because of its high exothermic onset temperature, and few possibilities of ignition are expected in normal drying operations, ignitions are still possible in the drying oven. One possibility is that the oven overheats the UN granules. A second possibility occurs if dust from the composition accumulates on the hot surfaces of the oven and ignites. Of course, it is also always possible that the composition may ignite from some unidentified sources.



(a) Risks under Normal Operations



(b) Risks When Handling Deviates from Normal

Figure 4. Risk profiles for manufacturing UN gas generant.

Small quantities of UN granules burn slowly under atmospheric pressure. If the drying oven is well designed, the damage level for granules is ranked at level III. In the granulating operation of an AK composition, decomposition in the mortar of the granulating machine has been observed. This decomposition made noise but did not affect the machine or the outside of the mortar. Such a decomposition may be caused by friction during the normal tabletting operations. Dissolving starch, mixing and kneading the raw materials, granulating the mixture and the amounts of materials involved should not cause accidents if operations are carried out normally.

Among the risks associated with operations that deviate from normal, the highest are associated with the drying operation. The causes of ignition include the use of an incorrectly designed oven, modification of the composition to an unstable one, contamination, and accumulation of dust on the hot surfaces of the oven.

If the oven is maintained improperly, the oven may overheat and the UN composition may ignite. If the inside of the oven is not kept clean, dust from the composition accumulates on hot surfaces and may ignite. If the composition is contaminated with a material which catalyzes a reaction, it may become unstable. If a component of the composition is modified, a safety assessment must be done on the new formulation to establish its stability. These types of deviation from normal operation must be prevented.

Additional problems to be considered are the violence of possible combustion reactions and the severity of the resultant damage. If UN granules are placed in an oven that is not the open design, an accidental ignition and subsequent burning of the granules may blow the oven door off and injure workers. It is crucial to use a properly designed oven for safe drying.

In the tabletting operation, decomposition is inevitable in the mortars of the machine. Decomposition in a mortar normally does not affect the outside of the device, but as the mass of the pellets increases, decomposition in the mortar may propagate and ignite granules outside the machine. Good maintenance and cleaning of the tabletting machine are important for preventing incidents during the tabletting operation.

The filling of bottles with UN pellets and the packaging of the bottles into containers has no risk other than that of external fire. The packaging will not promote fire.

If too high an inventory of the UN powders, granules or pellets is maintained, these materials become a hazard because of their rapid combustion. This is known for the AK gas generant as well.[16] This is especially the case if the generants are sealed tightly in a container. One should avoid both over-inventory and the use of sealed vessels in processing.

If dry raw materials are mixed without adding water, the possibility of ignition exists, and burning the dry mixture may blow the cover of the mixing machine. The damage will be more severe if a machine with tight seals is used.

Workers must be informed of the hazards associated with incorrect mixing of components. For example, mixing oxidizing materials with additive 1 yields deflagrating mixtures. This must be avoided.

Hot water is used in dissolving soluble starch. In general, hot water is handled in a closed system and, therefore, there is little hazard. If a container is broken or inadequate precautions are taken, water may spill and potentially scald those working with it.

The granulating machine may become heated if the water content of the composition is inadequate. The water content of the mixture must be controlled and the machinery must be regularly maintained to insure safe operation.

8. Prevention of Deviations from Normal Operation and Corrected Risk Profile

From the consideration of the risk catalog and profiles of the normal operation and deviations from it, we suggest measures for preventing deviations and for promoting safety of operations at acceptable levels.

8.1 Safety Measures for Drying Operations

Two measures for preventing accidents during the drying operation have been identified. One is preventing the occurrence of ignition in the oven as follows:

1) Select an oven with good temperature control.
2) Select an oven without hot, exposed surfaces.
3) Prevent the accumulation of dust in the oven.
4) Use a composition of known stability.
5) Prevent contamination which makes the composition unstable.

A second is to prevent damage when ignition accidentally occurs:

1) Use an oven without a tight seal.
2) Limit the amount of granules in the oven.
3) Use an oven with a safe door.
4) Prevent anyone from approaching the safety relief opening of the oven when the drying operation is in progress.

8.2 Safety Measures for Inventory

It is important to let involved people know the consequences of deviations in the amount of materials on hand and the necessity of keeping a fixed inventory.

8.3 Safety Measures for the Tabletting Operation

Ignitions in tabletting machines are quite common. It is important that the machine is designed so that ignition does not propagate.

As the tabletting machine is apt to malfunction, appropriate personnel must be in charge of the machine and must maintain it in optimum condition. Workers should be educated and trained in preventing the accumulation of dust, granules and pellets around the machine.

8.4 Safety measures for the Granulating Operation

In the normal operation, granulating is safe because it is carried out on a mixture wet with water. However, the material in the machine may be subjected to excess pressure, friction or high temperature if the amount of water present is inadequate. It is important for appropriate personnel to be aware of these factors and to keep the machine in optimum condition to carry out the granulating operation safely.

8.5 Safety Measures for the Kneading Machine

The order in which raw materials are fed into the kneader must be strictly fixed. Additive 1 should not be mixed directly with KNO_3 or additive 2. The workers must be educated thoroughly in this regard. The kneader sometimes heats up during operation. Excess heating indicates a deviation from normal operations, and it is essential that the cause be determined and removed.

8.6 Safety Measures for Dissolving Starch

The dissolving vessel should have a structure that allows no spills of hot water. This should present no problems if the equipment is correctly designed.

8.7 Corrected Risk Profile

A corrected risk profile for the manufacturing process of a UN gas generant was produced according to the suggestions in this paper and is shown in Figure 5.

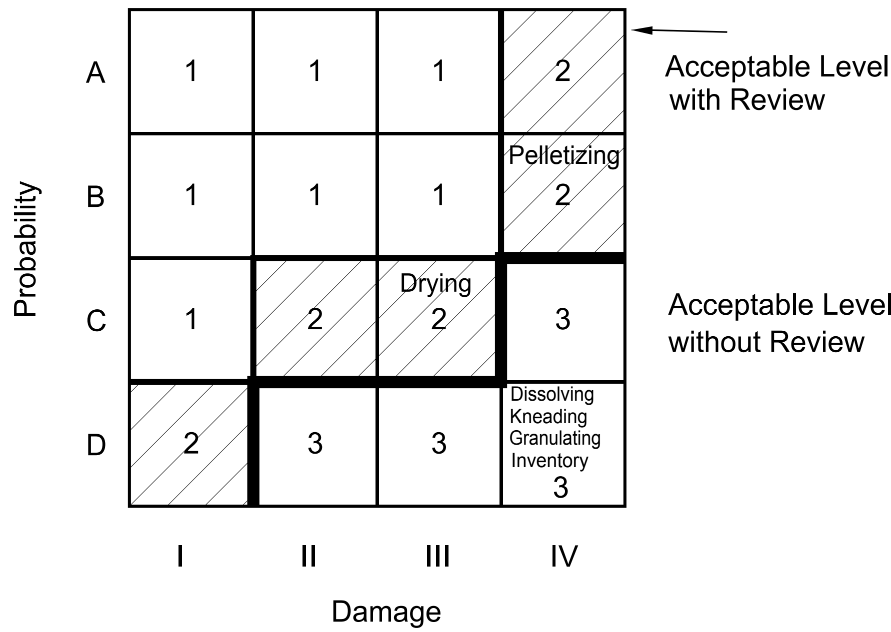


Figure 5. Corrected risk profile for manufacturing of UN gas generant.

9. Conclusion

A hazard analysis has been carried out for the manufacture of a UN gas generant in a batch 100 kg in size. The following conclusions were reached:

1) The UN gas generant can be manufactured safely if the appropriate people have information on the hazards associated with the materials and the normal operations used in the process and avoid deviations from normal operating procedures.
2) The drying operation has the highest associated risk among the operations in the process. The design of the oven, its use, and the thermal stability of the formulation are also important.
3) The order in which the raw materials are blended is important.
4) Good maintenance of the tabletting and granulating machines is crucial.

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Errata — Issue No. 3

Page 39: In the formula, (A_e) should be (A_b).

The correct formula is:

$$P=B\left(\frac{A_b}{A_t}\right)^{\frac{1}{1-n}}$$