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Role of pesticide formulations for sustainable crop protection and environment management: A review

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Abstract
The role of pesticides in preventing crop losses, making available food at cheap rates and improvement in quality of food cannot be overemphasized. Development and identification of new pesticide molecules has reached to almost a saturation point. This has brought the importance of pesticide formulations to the fore. The purpose of formulating pesticide active ingredients for crop protection is to uniformly spread a small amount of an active chemical over a large area. The goal is to ensure safety in handling and during application and to optimize pesticide efficacy. This requires that the pesticide formulation be chemically stable and physically uniform under all foreseeable storage conditions so that the minimum effective amount can be accurately applied to target areas.

Keywords: Pesticide formulations, formulation trends, conventional formulations, surfactants, adjuvants

1. Introduction
Importance of continued development in pesticide science is more in a country like India which is predominantly agricultural with about 80% of the population depending upon agriculture and living in rural areas. Indian population is expected to cross the 125 crore mark by 2020 AD, with the corresponding requirement of food grains exceeding 220 million tones. As against this, the availability of land per capita is expected to be 0.14 hectares. Under this critical situation the role of pesticides in preventing crop losses, making available food at cheap rates and improvement in quality of food cannot be overemphasized. Besides ensuring the food supplies, pesticides have also to make as substantial contribution in increasing the production of cash crops like cotton, tea, coffee, spices, tobacco etc., which in addition to meeting the domestic requirement are so important for export earnings. Development and identification of new molecules has reached to almost a saturation point. It has been estimated that around 250 million dollars and 8-10 years are needed for the development and production of a new molecule and to bring it into the market. This has brought the importance of pesticide formulation to the fore.

2. Formulation
Pesticides are available in various "formulations". A formulation is simply the form of a specific product that offers for sale. Some insecticide formulations include dusts, gels, granules, liquids, aerosols, wet table powders, concentrates, and pre-mixed solutions. Most of the technical pesticides are formulated before use, by mixing active ingredients, with inert, diluents, preservative, adjuvant, etc to obtain a product which is effective, easy to handle and apply, possesses satisfactory shelf life, and is devoid of undesirable side effects.

2.1 Why should we formulate a pesticide?
Pesticide formulation is the process by which the pesticide is put into a form which can be easily produced, stored, transported and applied by practical method in order to achieve safe, convenient and effective method of pest control in an economical way. To convert it into a product which can be stored, transported and applied by practical methods to achieve effective, safe and economic use

2.2 Choice of the type of formulation
The importance of formulation type is generally over looked. A well-considered decision to use the most appropriate formulation for a given application requires detailed analysis of the following factors (Agrow Report 2001).
1. Biologically effective
2. Manufacturing convenience

2.2.1 Formulation design inputs

- Compound Inputs: Physical, Chemical & Biological properties.
- Application input: Pest, Plant, Equipment, Climatic, and Public Health.
- Marketing Input: User friendly, Attractiveness, Safety, Durability, Economy.
- Manufacturing Input: Production Equipment, QC facilities.

2.2.2 Steps for development (formulation)

- Preliminary Studies– Lab preparation, Physical & Chemical tests
- Investigational Stage – Bio-efficacy, Phytotoxicity, Shelf Life, Analytical Method Development, Small scale field trials, Toxicology
- Commercial-Process of Formulation, Tank mix compatibility, Packaging development

2.2.3 Requirements of well-designed formulations

- Should be biologically effective when used as recommended with no undesirable side effects.
- Presented in form where active ingredients give maximum biological effect at min. cost.
- Should be applicable by chosen means to provide effective and reliable dispersion.
- Large scale manufacture at acceptable cost.
- Should be safe during manufacture, packing, storage and transportation.
- Should have adequate shelf life.
- Should be acceptable to registration authorities and consumer.

2.3 Types of formulations

Collaborative International Pesticides Analytical Council (CIPAC) propose 65 nos. of formulation types and their coding system (Table 1).

Table 1: Catalogue of pesticide formulation types and international coding system

AE	Aerosol dispenser	MC	Mosquito coil
AL	Other liquids to applied undiluted	ME	Micro-emulsion
AP	All other products to be applied undiluted	MR	Matrix Release
BR	Briquette	OD	Oil dispersion
CB	Bait concentrate	OF	Oil miscible flowable concentrate
CP	Contact powder	OL	Oil miscible liquid
CS	Capsule suspension	OP	Oil dispersible powder
DC	Dispersible concentrate	PA	Paste
DP	Dustable powder	PR	Plant rodlet
DS	Powder for dry seed treatment	RB	Bait (ready for use)
DT	Tablets for direct application	SC	Suspension concentrate (= flowable concentrate)
EC	Emulsifiable concentrate	SD	Suspension concentrate for direct application
EG	Emulsifiable granule	SE	Suspo-emulsion
EO	Emulsion, water in oil	SG	Water soluble granule
EP	Emulsifiable powder	SL	Soluble concentrate
ES	Emulsion for seed treatment	SO	Spreading oil
EW	Emulsion, oil in water	SP	Water soluble powder
FS	Flowable concentrate for seed treatment	ST	Water soluble tablets
FU	Smoke generator	SU	Ultralow volume (ULV) suspension
GA	Gas	TB	Tablet
GD	Gel for direct application	TC	Technical material
GE	Gas generating product	TK	Technical concentrate
GL	Emulsifiable gel	UL	Ultra-low volume (ULV) liquid
GR	Granule	VP	Vapour releasing product
GS	Grease	WG	Water dispersible granule
GW	Water soluble gel	WP	Wettable powder
HN	Hot fogging concentrate	WS	Water dispersible powder for slurry treatment
KK	Combi-pack solid/liquid*	WT	Water dispersible tablets
KL	Combi-pack liquid/liquid*	XX	Others
KN	Cold fogging concentrate	ZC	A mixed formulation of CS en SC
LB	Long-lasting storage bag	ZE	A mixed formulation of CS en SE
LN	Long-lasting insecticidal net	ZW	A mixed formulation of CS en EW
LS	Solution for seed treatment		

* Special two-letter code for twin-packs

Pesticides in developing countries of Asia and Pacific region are mainly available as dust, wettable powder, emulsifiable concentrate, solution etc (Seaman, 1990) [27]. These types of formulations are now known as 'conventional' or 'old technology' or 'classical' or 'traditional' because of their increased dose or repeated applications to get desired bio-efficacy (Rüegg *et al*., 2007) [27]. More than 70% pesticides flow into the environment and residue in plant products in process of application through old formulations. Inefficient use of pesticides causes a series of food safety and environmental problems (Gupta 2004) [11]. With the increasing awareness of toxic effects of conventional formulations, there is a significant trend towards switching over from such old herbicide formulations using petroleum and organic solvent based constituents to user and environment friendly smart and innovative herbicide formulations (Green *et al*., 2007) [10].

2.3.1 Conventional Formulation

Conventional pesticides are among the most popular chemical control agents because they are readily available, rapid acting, and highly reliable active ingredients other than biological

pesticides and antimicrobial pesticides. Conventional active ingredients are generally produced synthetically, i.e., are synthetic chemicals that prevent, mitigate, destroy, or repel any pest; or that act as a plant growth regulator, desiccant, defoliant (EPA). A single application may control several different pest species and usually forms a persistent residue that continues to kill insects for hours or even days after application. Because of their convenience and effectiveness, insecticides quickly became standard practice for pest control during the 1960's and 1970's. Conventional formulations includes Dustable Powder (DP), Emulsifiable concentrate (EC), Wettable powder (WP), Soluble (liquid) concentrate (SL), Soluble powder (SP), etc.

2.3.1.1 Dustable Powder (DP)

Dusts (D) are formulated as ready-to-use pesticides, with no dilution required. The active is either a crystalline solid ground to 1-10 micrometers, or a liquid or waxy compound absorbed onto an inert mineral carrier. The concentration of active is typically less than 10% by weight, with a finely ground mineral diluent making up the balance. Aerial application of dusts was once commonly practiced, but this has all but been abandoned due to inhalation hazards and the tendency of dusts to drift into non-target areas. Today dusts are used for small area treatment such as gardens, for seed treatments and for the control of parasites on pets and livestock.

Dusts are manufactured by the sorption of an active ingredient onto a finely ground, solid inert such as talc, clay, or chalk. They are relatively easy to use because no mixing is required and the application equipment (e.g., hand bellows and bulb dusters) is lightweight and simple. Since these formulations are not diluted with water before application in the field so the particle size of these formulations are higher (approximately 25 to 35µ) as compared to wettable powder formulations (approximately 5 to 10µ). Dusts can provide excellent coverage, but the small particle size that allows for this advantage also creates an inhalation and drift hazard. In general, dust formulations are no longer used in large-scale outdoor situations due to their high drift potential; however, dusts are still applied as spot treatments for insect and disease control outside. Commercial pest control operators use dusts effectively in residential and institutional settings for control of various insect pests. Indoors, this type of formulation permits the delivery of an insecticide into cracks and crevices, behind baseboards and cabinets, etc. Thus, the insecticide is placed into the pest's habitat and away from contact by people and pets. Example: BHC 5% DP, Carbaryl 5% DP, Malathion 5% DP. Drawbacks of DP formulation as;

- Bulky
- Hazardous dust clouds formed on application
- Drift downwind
- Difficulty in handling

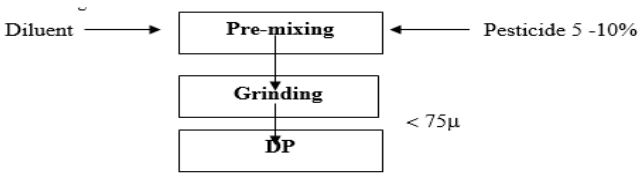

Fig 1: Schematic diagram of Processing of DP formulation

2.3.1.2 Wettable powders (WP)

Wettable powders are finely divided solids, made of mineral clays to which an active ingredient is mixed/ sorbed. These formulations are diluted with water and applied as a liquid spray. Upon dilution, a suspension is formed in the spray tank. Beside active ingredient wettable powders contain wetting and dispersing agents as an inert- part of the formulation. These are chemicals, which help in wetting the powder and disperse the active ingredient throughout the spray tank. Wettable powders are the oldest and very common type of formulations. They provide an ideal way to apply an active ingredient in spray form of the constituents, which are insoluble in water. Wettable powders tend to pose a lower dermal hazard in comparison to liquid formulations, and they do not burn vegetation as readily as many solvent based formulations. Eg. Thiophenate methyl 70% WP, Sulphur 80% WP, Isoproturon 75% WP. There are some drawbacks of DP formulation as;

- Hazardous dust clouds [while processing, packing and application]
- Low bulk density
- Poor wettability
- Handling problems

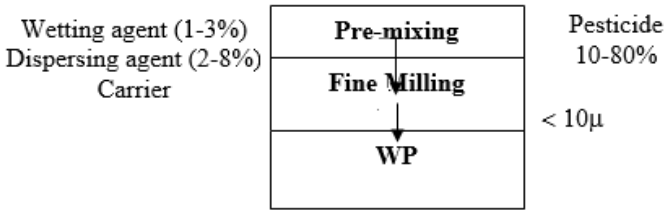

Fig 2: Schematic diagram of Processing of WP formulation

2.3.1.3 Soluble Powder (SP)

A soluble powder formulation (SP) is defined as a powder formulation to be applied as a true solution of the active ingredient after dissolution in water, but which may contain insoluble inert ingredients. Normally, however, water-soluble fillers are used. Soluble powders are cheap and relatively easy to produce, contain no solvent and are tolerant to extremes of temperature. Application is usually straightforward since all formulation components, including active ingredient, are water-soluble, at least at spray tank dilutions. Consequently, unlike water-dispersible powders there is little risk of sludge formation and blockages of line filters and spray nozzles. However, as powders they suffer from similar dust problems to water-dispersible powders and are tending to be replaced by less hazardous formulations such as soluble granules (SG), or else packed in water-soluble bags (Eg. Methomyl 40%SP, Aureofungin 46.15%SP, Cartap Hydrochloride 50%SP)

2.3.1.4 Emulsifiable Concentrates (EC)

Emulsifiable Concentrates (EC) are blends of pesticide, emulsifiers and adjuvants dissolved in a volatile oil. Low melting point or liquid pesticide actives have traditionally been formulated into EC's. When the EC is added to water in the spray tank, it forms a stable dilute emulsion. ECs are a convenient means of using water as a vehicle for oil-soluble pesticides. The emulsifying agents are long-chain chemicals that orient themselves around the droplets of oil and bind the oil-water surfaces together to prevent the oil and water from separating. They are not abrasive to application equipment, nor do they plug screens and strainers. However, their oily solvent base creates several hazards: ECs can be absorbed through the skin, burn foliage, and attack the rubber and plastic parts of spray equipment. Eg. Cypermethrin 25% EC,

Hexaconazole 5% EC, Butachlor 50% EC. Few drawbacks of EC formulations as;

- Presence of solvent
- Dermal toxicity
- Inflammability
- Non-biodegradable
- VOC

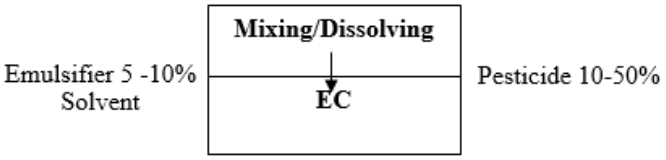

Fig 3: Schematic diagram of Processing of EC formulation

2.3.1.5 Soluble Liquid (SL)

Soluble liquids are usually water-based products that contain a water soluble active ingredient. This is one of the formulation types that actually contain dissolved molecules, not suspended particles. They mix easily in water and require minimal agitation after dilution, though some actives are dense enough to settle out over time. The process of making same as EC formulation.

Eg. Ethephon 39% SL, Phosphamidon 40% SL, Kasugamycin 3% SL. Few drawbacks of SL formulations as;

- Expensive to pack & transport
- Cannot contain high a.i. concentration
- Poor wetting & spreading
- Poor rainfastness

2.3.1.6 Newer Trends in Formulations

An extensive work is being carried out worldwide, for developing new formulation technologies which would serve the objectives of easier application, labour saving, improved safety, reduced toxicity, minimization of environmental pollution, higher efficacy and reduced cost. The areas of development include suspension concentrates, microemulsions, granules, microgranules, water dispersible granules, concentrated emulsions, controlled release, gels, tablets etc. and mixed formulations like ZC, ZE, and ZW.

- More effective
- Safer
- Easier to handle

2.3.1.7 Water Dispersible Granules [WDG]

Water dispersible granules (WDG), or dry flowables (DF), are wettable powders that have been aggregated into uniform granules of size 1-2mm for easier handling and to eliminate respirable particles. They are dispersed in the spray tank and applied as dilute suspensions in the same way as wettable powders. WDGs incorporate the same ingredients as wettable powders, including dispersants and clay, although generally with a higher level of active and less diluent. The granules must be strong enough to resist crumbling into powder, yet still readily and completely disintegrate and disperse in the spray tank. This avoids nozzle clogging and ensures the finest particle size of the active ingredient for optimum efficacy. Several methods are used to form granules from the starting powder blend. These include pan granulation, fluid bed granulation, spray drying, high speed mixer agglomeration and extrusion granulation. Extrusion granulation is generally preferred on the basis of safety, versatility and economy. They are becoming more popular because of their convenience in packaging and use, capable of high a.i. (50 – 90%), being non-dusty, free flowing granules which should disperse quickly when added to water in the spray tank. Examples of WG; Sulphur 80% WG, Sulfosulfuron 75% WG, Thiamethoxam 25% WG. Process of making, advantages and disadvantages of WDG represented in Table 2. There are several advantages of WDG compared to WP formulations as;

- dust free
- ease of measuring and handling
- empties out completely from the container
- less chance of spillage

Whereas advantages of WDG compared to SC formulations as;

- better physico-chemical stability
- higher concentration
- easy pack disposal

Composition of WDG is as follows;

Active ingredient	50 to 90%
Dispersing agents	5 to 15%
Wetting agents	1 to 3
Binder	0 to 2%

Table 2: Process of making, advantages and disadvantages of WDG

Process	Advantages	Disadvantages
Spray granulation [Spray / Fluid bed granulator]	Good dispersibility Free flowing	Low density, medium resistance to attrition
Extrusion	High density Good resistance to attrition	Poor spontaneity to dispersion
Pan granulation	Good dispersibility Medium density	Poor resistance to attrition Dusty

2.3.2.2 Suspension Concentrates [SC]

Suspension Concentrates [SC] or Aqueous flowables (AF) are concentrated 40% to 70% w/w suspensions of micronized active pesticide in water. Prior to spraying on target areas, aqueous flowables are diluted with water in a spray tank to achieve the minimum effective pesticide concentration. AFs must be formulated for low viscosity and good fluidity so that transfer to the spray tank is easy and complete. This requires an effective wetting agent and an efficient dispersing agent to ensure adequate dispersion of the pesticide in the water. Since the active ingredients in AFs are insoluble, good suspension stability is essential. If the suspension settles and leaves sediment at the bottom of the container, the application of the pesticide may be too weak to be effective. Also, disposal of the residue in the container becomes a problem. A combination of smectite clay (aka bentonite) and xanthan gum works synergistically to provide excellent long term suspension stability at low viscosity and at low cost. Developing a flowable is a balancing act between the need to keep the viscosity high enough that particles do not sink rapidly, but low enough that the material pours out or pumps easily. Few Examples of SC formulations are Carbendazim 50% SC, Deltamethrin 2.5% SC, Isoproturon 50% SC. Concentrated suspension of finely divided pesticide in water

- *Average particle size - < 2 microns*
- *Concentration – 10 to 50%*

The main advantages of SC formulations are;

- Dust free
- Handling ease

- Low packing volume
- Excellent dilution properties
- No problem of toxicity or flammability due to solvents
- Improved bio-efficacy
- Finer particle size
- Better adhesion

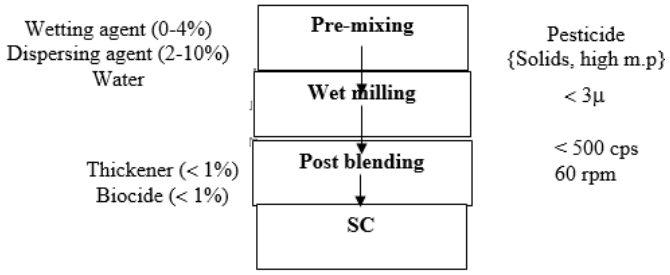

Fig 4: Schematic diagram of Processing of Processing of SC formulations

2.3.2.3 Microencapsulated Suspensions [CS]

Microencapsulated pesticides are mixed with water and sprayed in the same manner as other sprayable formulations. After spraying, the capsule wall breaks down and slowly releases the herbicide. Microencapsulated materials have several advantages like highly toxic materials are safer for applicators to mix and apply, delayed or slow release of the herbicide prolongs its effectiveness, allowing for fewer and less precisely timed applications and herbicide volatilizes more slowly; less is lost from the application site. These are concentrated suspension / dispersion of pesticide microcapsules in water which can be diluted and sprayed. (E.g. Lambda cyhalothrin 2.43 % CS, 4.9%CS, Pendimethalin 38.7% CS). The main Advantages of CS formulations are;

- Reduced mammalian toxicity
- Extended activity
- Reduced phytotoxicity
- Reduced evaporative losses
- Reduced leaching
- Lower doses

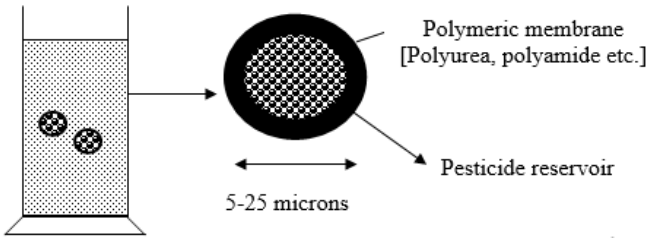

Fig 5: Schematic diagram of Processing of CS formulation

2.3.2.4 Concentrated emulsions (EW)

Concentrated emulsions (EW) contain up to 50% w/w of oil-soluble pesticide. EWs minimize the disadvantages of emulsifiable concentrates by minimizing the level of solvent needed to dissolve the pesticide, and then emulsifying this solution in water. With an EW, the emulsion has already been established in the sold product, and is only diluted in the spray mixture (Gasic *et al*., 2006). Because they are water based, oil-in-water emulsions can have significant advantages over emulsifiable concentrates in terms of cost and safety in manufacture, transportation and use (Zhang 2004) [33]. The combination of smectite clay and xanthan gum stabilizes the concentrated emulsion against separation in the same way that it stabilizes concentrated AF suspensions. To prepare the concentrated emulsion, the smectite clay is hydrated in the water phase before the emulsion is formed. The xanthan gum can be dissolved in the water either before or after emulsification. EWs can also be in the form of either micro or macro-emulsions. However, EW-formulations are uncommon, because few active substances are liquids or possess the suitable solubility properties (Eg. Butachlor 50% EW; Tetraconazole 3.8% EW, Pretilachlor 37% EW). The main advantages of EW formulations are;

- Reduced dermal toxicity
- Less irritant to skin & eyes
- Less phytotoxic
- Not inflammable
- Environmentally safer

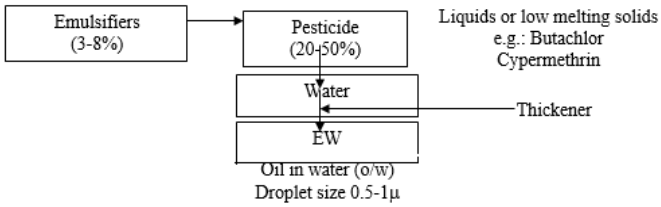

Fig 6: Schematic diagram of Processing of EW formulation

2.3.2.5 Microemulsions (ME)

Microemulsions are thermodynamically stable water-based systems containing water-insoluble pesticides. In addition, microemulsions are composed of extremely tiny particles (similar to micelles) that can be as small as 0.01 micron. This makes the diluted product transparent because light scattering is reduced. It is commonly believed that microemulsions can provide superior efficacy relative to macroemulsion formulas having the same level of activities. It is believed that the small size of the emulsion droplets may allow for better transport of the herbicide through cell membranes thereby resulting in enhanced efficacy. Microemulsions are considered to be infinitely stable, thereby providing improved stability over traditional macroemulsion systems. Composition of microemulsions as;

- Liquid pesticide or solution in solvent
- Emulsifier
- Co-surfactant
- Water

2.3.2.6 Oil Disperson (OD)

An oil dispersion (OD) formulation is a solid a.i. dispersed in oil. The oil can vary from paraffinic to aromatic solvent types and vegetable oils. Ideally the active ingredient is uniformly suspended in the oil phase. Water free formulation (the a.i. which are very sensitive in water useful in this formulation), Can suffer from more sedimentation compared to water based systems. (Eg. Beta cyfluthrin 8.49% + Imidacloprid 19.81% OD; Cyantraniliprole 10.26% OD)

2.3.2.7 Concentrated Aqueous Emulsion (EW)

They can be considered as a safer and more environmentally friendly alternative to EC. In an EW the continuous phase is water which offers the benefit of lower phytotoxicity, no flashpoint concern, ease of handling, and a lower environmental impact. EW formulations are physically stabilised by polymeric surfactants incorporated at an appropriate level. The emulsion has already been established in the formulation and is only diluted further in the spray mixture. Examples of EW formulation; Carfentrazone ethyl

0.43% + Glyphosate 30.82% EW, Butachlor 50% EW, Cyfluthrin 5% EW.

2.3.2.8 Aqueous Suspo-emulsion (SE)

Dual character heterogeneous formulations, combination of suspension concentrate (SC) and concentrated aqueous emulsion (EW) consisting of a stable dispersion of active constituent(s) in the form of solid particles and fine globules in a continuous. Two active ingredients with very different physical properties are existing into one formulation. The advantages are that it is possible to formulate multiple active ingredients together, broadening the spectrum of activity and eliminating the disadvantage of tank-mix incompatibility. Examples of SE formulation; Carbendazim 25% + Flusilazole 12.5% SE, Fenobucarb 20% +Buprofezin 5% SE, Propiconazole 10.7% + Tricyclazole 34.2% SE.

2.3.2.9 Multi-character liquid formulations: Mixed formulations

A. ZC formulation

ZC is a mixed formulation of Capsule Suspension (CS) and Suspension Concentrate (CS) and is a stable aqueous suspension of microcapsules and solid fine particles, each of which contains one or more active ingredients. The formulation is intended for dilution into water prior to spray application. Formulating the active ingredients together eliminates the need for tank mixing, which can lead to incompatibility, and facilitates control of a wider range of pests with fewer applications. Like other aqueous liquid formulations, ZC formulations are easy to handle and measure, dust free, non-flammable and offer good miscibility with water. The advantage of ZC formulations is to formulate multiple active ingredients together to deliver two complementary modes of action for broad-spectrum control of key insects. Example of ZC formulation; thiamethoxam 12.60% + lambda-cyhalothrin 9.48% ZC.

B. ZE formulation

ZE is a mixed formulation of Capsule suspension (CS) and Suspo-emulsion (SE) and is a stable aqueous dispersion of microcapsules, solid fine particles and emulsion droplets, each of which contains one or more active ingredients. The formulation is intended for dilution into water prior to spray application. Formulating the active ingredients together eliminates the need for tank mixing, which can lead to incompatibility, and facilitates control of a wider range of pests with fewer applications. Like other aqueous liquid formulations, ZE formulations are easy to handle and measure, dust free, non-flammable and offer good miscibility with water. Individual formulate and after that mixed them Capsule suspension and Suspo-emulsion. By this procedure one can use three a.i. (one in capsule) and one in suspension concentrate and third one in emulsion in a single formulation.

C. ZW formulation

ZW is a mixed formulation of Capsule suspension (CS) and Concentrated aqueous emulsion **(**EW) and is a stable aqueous dispersion of microcapsules and emulsion droplets, each of which contains one or more active ingredients. The formulation is intended for dilution into water prior to spray application. Formulating the active ingredients together eliminates the need for tank mixing, which can lead to incompatibility, and facilitates control of a wider range of pests with fewer applications. Like other aqueous liquid formulations, ZW formulations are easy to handle and measure, dust free, non-flammable and offer good miscibility with water. One or more of the active ingredients is encapsulated for various purposes, such as to increase the residual biological activity, or to reduce the acute toxicity, or to obtain a physical or chemically stable water-based formulation. The purpose determines whether the "free" active ingredient and the "release rate" are relevant properties of a specific product.

3. Use of Adjuvants

An adjuvant is an additive (usually in relatively low amounts compared to the carrier) which are added to make the formulations more effective, that improves or enhances application, performance, safety, storage, or handling of an active ingredient. Adjuvants include materials such as; binders, stickers, stabilizers, antifreeze, antifoam, etc. These additives are commonly categorized as *utility* or *activator* adjuvants. Activators can be thought of as products that improve herbicide performance after the spray has contacted the leaf surface. Utility adjuvants improve your ability to get the herbicide to the leaf surface. Activator adjuvant products perform several functions - they serve as wetting agents (or spreaders), stickers, humectants and penetrants. A wetting agent reduces the surface tension of water, so that a droplet beads less, lays flatter on the leaf surface, and covers more leaf surface area. A sticking agent helps the herbicide ingredients, particularly dry ingredients that were suspended in water, stay on the leaf surface after the water has evaporated. The sticking agent remains as a thin film holding the herbicide in place so that it can be absorbed, and prevent wash-off. A humectant retains moisture, or absorbs water vapor from the air to prevent reduce net evaporation. Keeping the deposited herbicide surrounded by moisture as long as possible prevents the herbicide from crystallizing on the leaf surface and increases absorption of the herbicide into the leaf. An oil-soluble penetrating agent increases the movement of the herbicide into and eventually through the cuticle so that the herbicide can absorbed into the outer layer of cells. Drift inhibitors or thickeners are used to control drift. These may be powders, granules, or liquids that cause the spray solution to be more cohesive; less subject to wind shear as it leaves the nozzles so as to reduce the amount of very small spray droplets.

4. Pesticide formulations in a nut shell

A. ***Dry*** formulations
B. ***Liquid*** formulations
C. ***Household*** formulations

A. Dry formulations

1. For direct use
2. For Dissolution
3. For dispersions

1. Dry formulations for direct use

- Dustable powders **(DP)**
- Powders for dry seed treatment (DS)
- Granules (GR)
- Tablets for direct application (DT)

2. Dry formulations applied after dissolution

- Water soluble powders (SP)
- Water soluble powders for seed treatment (SS)
- Water soluble granules (SG)
- Water soluble tablets (ST)

3. Dry formulations applied as dispersions

- Wettable powders (WP)

- Water dispersible powders for slurry seed treatment (WS)
- Water dispersible granules (WG)
- Water dispersible tablets (WT**)**

B. Liquid formulations

1. Simple solutions
2. Solutions for dispersions
3. Emulsions
4. Suspensions

1. Liquid formulations applied as simple solutions

- Soluble concentrates (SL)
- Solutions for seed treatment (LS)
- Oil miscible liquids (OL)
- Ultra low volume liquids (UL)

2. Solutions applied as emulsions

- Emulsifiable concentrates (EC)

3. Liquid formulations - Emulsions

- Emulsions, oil in water (EW)
- Emulsions for seed treatment (ES)
- Micro-emulsions (ME)

4. Liquid formulations - Suspensions

- Aqueous suspension concentrates (SC)
- Suspension concentrates for seed treatment (FS)
- Oil-based suspension concentrates (OD)
- Aqueous capsule suspensions (CS)

5. Dual character formulations

- aqueous suspo-emulsions (SE)-mixed formulations of SC and EW
- mixed formulations of CS and SC (ZC)
- mixed formulations of CS and EW (ZW)
- mixed formulations of CS and SE (ZE)

C. Household Formulations

1. Aerosols (AE)
2. Mosquito Coils (MC)
3. Vaporizer Mats (VM)
4. Liquid Vaporizers (LV)
5. Long lasting insecticidal Nets (LN)
6. Gels (PC)

5. Trends in Formulations Development

1. From WP to SC

Dust free, user friendly product

2. From EC to EW

No / minimum toxic, inflammable solvents

3. From WP & SC to WG

Dust free, stable product with minimum container disposal problems

4. Increased use of CS formulations

Extended residual effects, low toxicity

5. WP / WG in Water soluble packaging

Minimum physical contact, precise dosing

6. From single component to multi-component mixes

Broad spectrum activities, avoid tank mixing

7. Incorporation of adjuvants

Improve wetting, spreading, penetration

6. Ideal Product should be

- Free from volatile solvents
- Very low operator exposure hazard
- Maximum biological activity at the lowest dose level
- Minimum of pack disposal problems

7. Conclusion

Development of new formulations and new fields of application for the pesticides already in existence may be comparable to the development of new pesticides. The cost and time required for the development of new formulations may be even less than that required for the development of new pesticides. Current resources are directed toward the development of safer pesticides, for the worker and for the environment, as well as toward more efficient application and formulation technologies. In the context of the steadily increasing demands of modern weed management, new, optimized variations on existing formulation types–and of course new concepts–will always be required. Formulation technology is an interdisciplinary scientific undertaking, with special relationships to the disciplines of colloid chemistry and interfacial physics, in which technical chemistry plays an essential role.

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