# NANOPARTICLE CARRIERS FOR DRUG ADMINISTRATION AND PROCESS FOR PRODUCING SAME

## Field of the Invention

The invention relates to nanoparticle carriers for oral administration of medically active compounds and/or other compounds.

## Background to the Invention

The spray-drying technique has seen wide application in the preparation of pharmaceutical powders, mostly for pulmonary drug delivery, with specific characteristics such as particle size, density and shape. It is a well-established method for producing solid powder by atomising suspensions or solutions into droplets followed by a drying process in flowing hot air.

Although most often considered as a dehydration process, spray-drying can also be used as an encapsulation method where active substances are entrapped in a polymeric matrix or shell. It is reported that several colloidal systems such as emulsions or liposomes were successfully spray dried with preservation of their structure using drying-aid agents, particularly sugars such as lactose, sorbitol and trehalose.

One of the merits of the spray-drying technique is that it is a cost effective and quick drying process applicable to a broad range of pharmaceutical products and leading to the production of a free flowing powder, characterized by very low water content,

preventing therefore the degradation of the active. This is meaningful for the development of long-term stable carriers, mostly when these carriers are in the range of nano scale, designed specifically for the delivery of active compounds at the site of interest.

Recently, it has been shown that the spray drying technique can produce nano scale solid particles and solid lipid nanoparticles loaded with active agents to be used as delivery systems for pulmonary airways. It is worthwhile to note that in most cases where this technique was applied to produce solid nanoparticles, it was, in fact, a drying process of nanocapsules obtained by other techniques. Thereafter the suspension of the nanoparticles was subjected to spray drying. This resulted often in the production of particles with very broad size range from nano to micron size, despite the presence of disaccharides as drying excipients in the formulation.

Recently, it was reported the spray drying of a liquid colloidal system in the drug delivery field, where a single emulsion (water-in-oil emulsion) containing DNA encapsulated in poly(lactic-co-glycolic acid (PLGA), was successfully spray dried. Another report was made on spray drying of a double emulsion (oil-in-water-in-oil or O/W/O), in the presence of lactose, aiming to preserve orange oil and in both cases the particles produced were in the micron size range.

A need has been identified for spherical nanoparticles having a narrow size distribution range, typically from 180 to 250 nm. Ideally such particles should have a substantially smooth surface and be free flowing.

## Summary of the Invention

The invention provides a process for the production of nanoparticle carriers for drug delivery, said nanoparticles being produced by:

- preparing a double emulsion of water-oil-water including one or more polymer which forms the basis of the nanoparticle carrier;
- blending the drug to be delivered into one or more of the emulsion phases;
- doping either the oil-phase or the outer-water phase with a carbohydrate; and
- spray drying the emulsion to form nanoparticles of a narrow particle size distribution of 100 nm to 1000 nm.

The nanoparticles thus produced may be multifunctional nanoparticles.

The carbohydrate may be a saccharide.

The saccharide may be a disaccharide.

The disaccharide may be lactose, maltose, isomaltose, mannobiose, trehalose, cellobiose, or the like.

The saccharide may be combined with a cationic biodegradable muco-adhesive polysaccharide.

The polysaccharide may be chitosan or derivatives thereof.

The oil-phase of the emulsion may be doped with a surfactant.

The water-phase of the emulsion may be doped with surfactant.

The surfactant may be a nonionic surfactant.

The surfactant may be based on acetylenic diol chemistry.

The surfactant may be a polymeric nonionic surfactant.

The polymeric nonionic surfactant in the water-phase may be polyvinyl alcohol (PVA), partially hydrolysed.

The polymer may be in the oil-phase of the emulsion.

The polymer in the oil-phase may be PLGA (poly(lactic-*co*-glycolic acid)).

Both oil-phase and water-phase polymers may be present.

The drug may be added to the oil-phase.

The drug may be a hydrophilic drug which is added to the internal water-phase.

The drug may be hydrophobic and may optionally be added to the oil phase.

The drug may be Rifampicin, Isoniazid, Ethambutol, or Pyrazynamide.

The outer water-phase of the emulsion may include polyethylene glycol (PEG).

The oil-phase may include stearic acid.

The nanoparticles thus formed may be substantially spherical.

The particle size distribution of the nanoparticles may be from 180 nm to 250 nm diameter.

The description of embodiments which follows should be interpreted broadly and not to limit the scope of the invention.

## SPECIFIC DESCRIPTION OF EMBODIMENTS OF THE INVENTION

### 1. Object of Experiment

For this experiment, anti-tuberculosis antibiotics including isoniazid (INH) ethambutol (ETH), pyrazynamide (PZA) and Rifampicin have been successfully loaded in polymeric core-shell nanoparticles of poly DL, lactic-co-glycolic acid (PLGA50:50), a biodegradable and biocompatible polymer, extensively used as a carrier. Submicron solid particles of PLGA incorporating INH (or Eth or PZA or RIF) have been obtained by spray drying straightforward a typical double emulsion water-in-oil-in-water (W/O/W).

In the formulation, chitosan, a cationic biodegradable muco-adhesive polysaccharide, was employed as absorption enhancer while lactose monohydrate was used as spray drying-aid. PVA was considered as the main stabiliser component of the double emulsion, while PEG was incorporated to increase the bio-circulation of the carrier.

Surfynol 104 PG-50 ™, as a co-surfactant, played a big role in decreasing the particle size towards the nanosize range while significantly narrowing the size distribution.

## 2. Materials and Methods

### 2.1 Materials

The frontline anti-tuberculosis drugs were purchased from Sigma. Poly, DL, Lactic-co-Glycolic Acid, (PLGA) 50:50 (Mw: 45000-75000) and chitosan low Mw, 85% de-acetylated, were both supplied by Sigma. Polyvinyl alcohol (PVA) (Mw: 13000-23000 and partially hydrolysed (87-89%) was also obtained from Sigma. Stearic acid supplied by Merck, Surfynol 104 PG-50 ™, a Gemini diol type surfactant, was supplied by Air Products. Polyethylene glycol (PEG) (Mw 9000) was purchased from BASF Chemicals. Lactose monohydrate supplied by Merck, was used as an excipient.

Dichloromethane, ethyl acetate and acetonitrile, analytical and HPLC grades were also supplied by Merck.

### 2.2 Methods

#### 2.2.1 Formulation

The preparation of nanoparticles was achieved by the method based on the interfacial polymer precipitation from a double emulsion W/O/W subsequent to the evaporation of the organic solvent. In this invention, the step of solvent evaporation and drying was combined in one step by applying the spray drying technique.

Briefly, 50mg of INH was dissolved in a 2ml of phosphate buffer solution (pH7.4), which was added to a solution of 100mg of PLGA (50:50) dissolved in 8ml of the organic solvent (DCM or ethyl acetate). An optional 2ml of 0.2%(w/v) of stearic acid can also be dissolved in the same solvent (DCM or Ethyl acetate). A drop of Surfynol 104 PG-50 ™ was intentionally added either to the PLGA oil phase or to the external aqueous phase containing PVA.

The mixture was subject to emulsification using the high speed homogeniser (Silverson L4R) at 5000 rpm for 3min to produce W/O emulsion. This first emulsion obtained was then immediately poured into an aqueous phase volume of a known concentration of PVA (1 or 2% w/v), PEG 0.5% w/v, chitosan and lactose aqueous solution in a defined volume ratio, and emulsified to form the double emulsion W/O/W again by means of the high speed homogenizer (Silverson L4R) at 8000rpm for 5min. The final emulsion obtained was directly fed through a spray dryer to produce nanoparticles using the conditions specified in Table 1.

**Spray drying**

A Büchi mini spray dryer model B-290 (Büchi Lab, Switzerland) with a standard nozzle (0.7 mm diameter) was used to produce the dry powders of the various formulations. The conditions used are compiled in Table 1:

**Table 1 Spray-drying process condition of B-290 Büchi Mini Spray Drier**

| Condition | Parameter |
|---|---|
| Atomizing air volumetric flow rate | 800 NL/h |
| Feeding rate | 1.0 mL/min |
| Aspirator rate | 100% |
| Inlet (outlet) temperature | 90 -110°C (53-63°C) |
| Pressure for atomisation | 6-7 bars |

The spray dryer was provided with a high performance cyclone, designed to get an excellent recovery of the material in the receiver vessel and reduce the adhesion of the product on the wall of the drying chamber.

**2.2.2 Particle size and size distribution**

Particle size and particle size distributions were measured by Dynamic Laser Scattering or Photon Correlation Spectroscopy using a Malvern Zetasizer Nano ZS (Malvern Instruments Ltd, UK). For each sample 3-5mg of spray dried powder were prepared by

suspending the particles in filtered water (0.2μm filter), vortexing and/or sonicating for 2 min if necessary. Each sample was measured in triplicate.

### 2.2.3 Zeta potential

The zeta potential of the particles was measured using the Zetasizer Nano ZS (Malvern Instruments Ltd, UK). For that a sample of 3mg of the spray dried nanoparticles was suspended in 1-2ml of de-ionised water and then vortexed or sonicated before the measurement. Each measurement was taken in triplicate.

### 2.2.4 Scanning electron microscope

Surface morphology of spray dried nanoparticles was visualized by scanning electron microscopy (LEO 1525 Field Emission SEM.). A small amount of nanoparticle powder was mounted on a brass stub using a double-sided adhesive tape and vacuum-coated with a thin layer of gold by sputtering.

### 2.2.5 Drug incorporation

The amount of the hydrophilic drug Isoniazid that was entrapped in the particle powder after the nanoencapsulation process was measured in triplicate using a spectrophotometric method (UV-Vis, Thermo Spectronic Heliosα). The encapsulation efficiency of INH in nanoparticles was determined as the mass ratio of the entrapped INH to the theoretical amount of INH used in the preparation. For that, 50mg of precipitated particles were re-suspended in 20 ml of deionised water, centrifuged

(10 000rpm/10C/5min) to remove the un-encapsulated drug and the supernatant was subject to UV-Vis Spectrophotometer, read at λ= 262nm for INH assessment. The encapsulated amount of INH was determined by subtracting INH in the supernatant from total initial INH amount.

**INH stability assessment using HPLC**

The stability of INH spray dried powders was assessed by reverse phase-high performance liquid chromatography-analysis (RP-HPLC) using Shimadzu machine supplied with Photodiode Array (PDA) detector.

The following characteristics were applied: a Column Phenomenex [(C18 (5μm); (250 x 4.6mm ID)], a mobile phase of 5% (v/v) acetonitrile with 95% (v/v) buffer $NaH_2PO_4$ (pH 6.8), at a flow rate of 1 ml/min and at a temperature of 30°C. The detection was performed using PDA at λ= 259nm, on a total injection volume of 20μl.

**3. Results and Discussion**

All spray drying runs produced nanoparticles with a size ranging from approximately 220 to 800nm. The concentration of the liquid feed did not show any influence on the size of particles as illustrated with samples where the PVA concentration was changed from 1 to 2%. Only the addition of lactose and Surfynol 104 PG-50 ™ demonstrated a significant impact on the size and the morphology of nanoparticles. Interestingly, just one drop of the Gemini surfactant added to the oil phase, drastically reduced the size and the size distribution of the product, irrespective of either the type of organic solvent or the concentration of PVA.

During all the sets of experiments beside the temperature, all other parameters of the spray dryer were kept constant. The mass ratio PLGA: INH (2:1) was also unchanged. The addition of lactose improved significantly the shape of nanoparticles. This effect was pronounced when dichloromethane was used as organic solvent.

The yields of the powder for all the formulations investigated were in the range of 40-70%.

The residual water content of selected samples, determined by thermal analysis, showed a very low level of moisture (~3%).

Results obtained from HPLC indicated the degradation of INH, possibly due to interaction with lactose. This challenge was overcome by capping the functional groups of lactose with chitosan, prior to their incorporation in the formulation.

The encapsulation efficiency of INH is approximating 60%.

### 3.1 Effect of solvent on particles size and morphology

The most commonly used organic solvents in double emulsion technique are dichloromethane (DCM) and ethyl acetate (EA).

Thus, we decided to monitor the size and the morphology of nanoparticles by varying the organic solvent. In all cases, when ethyl acetate was used as organic solvent, the

first emulsion obtained presented an aspect of a transient stable emulsion, this observation being based on the less milky appearance of the emulsion when compared to the one obtained with DCM.

EA samples produced very irregular surface morphology compared to samples prepared with DCM. Particles from EA were highly dimpled and wrinkled before addition of lactose. Small doughnut-shaped particles were also observed

**3.2 Effect of additives**

**3.2.1 Effect of lactose on particle size and morphology**

The size and the shape as well as surface morphology of nanoparticles were strongly affected by the composition of the phases. As the initial concentration of lactose was increased from 5 to 10% w/v, the particles shifted from highly wrinkled to nearly smooth spheres. The fraction of doughnut-shaped particles decreased sensibly, regardless the type of solvent used, as depicted by SEM pictures in Fig. 1C and D. However, much more surface smoothness has been observed with DCM in the scale of observation.

The particle size decreased as we compared with formulations without addition of lactose, regardless of the type of organic solvent used. The decay was much more pronounced in case of DCM as illustrated by results presented in Figure 2: the z-average size of particles dropped from more than 1200 nm to 450nm, when lactose was added to the formulation.

Zeta potentials were in the positive range because of the presence of chitosan in the formulation. Its initial concentration was varied between 0.05, 0.1 and 0.3% (w/v) and the optimisation of the formulation was done with chitosan 0.3%, which resulted in a high positive zeta potential ~ +45mV.

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**3.2.2 Effect of Surfynol 104 PG-50 ™ on particle size and yield**

Nonionic surfactants, based on acetylenic diol chemistry, represent a unique class of surfactants providing low surface tension and good de-foaming and surface wetting
10 characteristics.

Contrary to most surfactants that orient vertically at the water/air interface, the acetylenic diol surfactants orient horizontally due to their molecular structure. A compact molecule of this surfactant can migrate very rapidly to the interfacial region providing
15 low values of the dynamic surface tension (DST). It was reported that for a Surfynol 104 PG-50 ™ bulk concentration of $2.10^{-6}$mol. $cm^{-3}$, the DST dropped around 35 dynes.$cm^{-1}$. It is, indeed, this specific property of significantly decreasing the surface tension which motivated us to select it as a co-surfactant in our formulations.

20 Surfynol 104 PG-50 ™ was added to the internal oil phase before introduction of the drug aqueous phase. The product obtained was characterised by a very small particle size about 230nm and the experimental results were reproducible.

The size distribution was equally very narrow (PolyDispersity Index (PDI) ~ 0.1) due
25 presumably to the capability of Surfynol 104 PG-50 ™to prevent aggregation.

### 3.2.3 Effect of PEG and Stearic acid on morphology

It is well established that polyethylene glycol (PEG) is extensively used in drug delivery strategies in order to generate entities which are less easily recognised by macrophages and hence exhibit prolonged circulation times in the blood. On the biological level, coating nanoparticles with PEG sterically hinders interactions of blood components with their surface and reduces the binding of plasma proteins with PEGylated nanoparticles. This prevents drug carrier interaction with opsonins and slows down their capture by the reticulo-endothelial systems (RES).

PEG was introduced together with PVA in the external phase at an initial concentration of 0.5%w/v, dissolved in de-ionised water

As we combine the presence of 5ml of PEG (0.5% w/v) in aqueous external phase and 2ml of stearic acid (0.2%w/v) added into the oily phase of the polymer, as a co-surfactant together with Surfynol 104 PG-50 ™, a significant improvement of the surface morphology was observed, as depicted in Fig. 3. The reading on Zetasizer provided smaller particles size of about 270nm with a very narrow distribution (PDI ~0.2).

**Claims**

1. A process for the production of nanoparticle carriers for drug delivery, said nanoparticles being produced by:

- preparing a double emulsion of water-oil-water including one or more polymer which forms the basis of the nanoparticle carrier;
- blending the drug to be delivered into one of the emulsion phases;
- doping either the oil-phase or the outer-water phase with a carbohydrate; and
- spray drying the emulsion to form nanoparticles of a narrow particle size distribution of 100 nm to 1000 nm.
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2. A process as claimed in claim 1, wherein the nanoparticles thus produced are multifunctional nanoparticles.

3. A process as claimed in claim 1 or claim 2, wherein the carbohydrate is a saccharide.

4. A process as claimed in claim 3, wherein the saccharide is a disaccharide.

5. A process as claimed in claim 4, wherein the disaccharide is selected from the group including lactose, maltose, isomaltose, mannobiose, trehalose, and cellobiose.

6. A process as claimed in any one of claims 3 to 5, wherein the saccharide is combined with a cationic biodegradable muco-adhesive polysaccharide.

7. A process as claimed in claim 6, wherein the polysaccharide is chitosan and/or derivatives thereof.

8. A process as claimed in any one of the preceding claims, wherein the oil-phase of the emulsion is doped with a surfactant.

9. A process as claimed in any one of the preceding claims, wherein the water-phase of the emulsion is doped with surfactant.

10. A process as claimed in any one of the preceding claims, wherein the surfactant is a non-ionic surfactant.

11. A process as claimed in claim 10, wherein the surfactant is based on acetylenic diol chemistry.

12. A process as claimed in claim 10, wherein the surfactant is a polymeric non-ionic surfactant.

13. A process as claimed in claim 12, wherein the polymeric non-ionic surfactant in the water-phase is PVA.

14. A process as claimed in any one of the preceding claims, wherein there is a polymer in the oil-phase of the emulsion.

15. A process as claimed in claim 14, wherein the polymer in the oil-phase is PLGA (poly(lactic-co-glycolic acid).

16. A process as claimed in any one of the preceding claims, wherein polymers are present in both the oil-phase and the water-phase.

17. A process as claimed in any one of the preceding claims, wherein the drug is added to the oil-phase.

18. A process as claimed in claim 17, wherein the drug is a hydrophilic drug which is added to the internal water-phase.

19. A process as claimed in claim 17 or claim 18, wherein the drug is hydrophobic.

20. A process as claimed in any one of the preceding claims, wherein the drug is selected from Rifampicin, Isoniazid, Ethambutol, or Pyrazynamide.

21. A process as claimed in any one of the preceding claims, wherein the outer water-phase of the emulsion includes polyethylene glycol (PEG).

22. A process as claimed in any one of the preceding claims, wherein the oil-phase includes stearic acid.

23. A process as claimed in any one of the preceding claims, wherein the nanoparticles thus formed are substantially spherical.

24. A process as claimed in claim 23, wherein the particle size distribution of the nanoparticles is from 180 nm to 250 nm diameter.

25. A process as claimed in claim 1, substantially as herein described.

26. A new process substantially as herein described.