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Dated. Oct.-2010.

Getting the most out of Coffee Hulls.
Drying Coffee Better & More Efficiently.
The Science of Gasification.

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Summary:

It is indeed possible, in a wet climate, to totally dry coffee with its own hulls, given suitable machinery and a direct fired combustion system.

If the coffee is totally machine dried a little slower and at a reduced temperature, no more than 45oC, the quality is equal if not better than most commercial coffee. Using coffee hulls more efficiently would eliminate the attack on native forest to supply firewood for coffee drying purposes. Unfortunately, currently available machinery is still based on the original designs of 200 years ago. Presently available new designs for grain driers, incorporating better combustion, counter current flow, and minimal torque requirements, could be considerably improved with minimal addition in cost over a new conventional coffee system.

Drying Arabica Coffee:

The drying of coffee is a subject fraught with a lot of inefficiency and ignorance. In those East African Countries where coffee is a traditional industry, starting at Ethiopia in the North, down to Zambia and Mozambique where sun drying is prevalent, there are mountains of surplus coffee hulls that just get burnt to waste. And in the wetter areas of the Globe, due to the inefficiency of the drying machinery, there is never enough hulls available, and the local peasantry make a poor living cutting down the native forest to supply firewood. The most pertinent comment to make at this point is that using efficient direct fired counter current drying methods, there is theoretically twice the heat energy available from dried coffee hulls to dry the same amount of wet parchment that they originally came from. Therefore the industry could be energy self sufficient, and not be subject to the anger of the 'Rain Forest Alliance' and other Environmental Agencies. In those areas where a certain degree of sun drying is possible, and that is of course still necessary to achieve premium quality, it is possible to generate a substantial amount of electricity from the gasification of coffee hulls, in addition to the finish drying of high quality first grade Arabica green bean. That makes for a **'Green & Earth Friendly'** fully sustainable product!

The Threefold Nature of the Problem:

There are three major points about coffee drying that make it a specialised area of machinery manufacture. Firstly, is the amount of moisture to be removed. Most cereal crops are ripened in the field and when they are harvested there is only 5-10% of moisture to be removed to get the grain down below the point where mould damage and other forms of spoilage are negated. This is usually around 11-12% MCDB. (Moisture content dry basis.) This means that a bed of drying grain can be several meters deep before the air leaving the system becomes fully saturated and it has lost all its sensible heat. The mathematics and analysis of such a design is ably given by Correa-Piedrahita[1]

Coffee berries are harvested and processed with water, and the material to be dried is wet parchment coffee, with a moisture content of around 55% MCWB.(Moisture content wet basis.= 117% dry basis). This means that more than 50% of the weight of the wet coffee has to be removed. Such large amounts cause a lot of shrinkage and severely limit the rate at which the coffee can be dried. Parchment cracking, stress hardening, case hardening of the beans themselves and oil extrusion from overheating are some of the faults caused by drying coffee too quickly and at too high a temperature. Details of these problems are outlined in my series entitled "The Microbiology of Coffee Processing" Good Coffee should not be dried at a temperature higher than 45^{o}C, and time should not be a limiting factor. It takes as long as it takes. When the market is flooded, in a good year and the price drops, the coffee that is first rejected and hits the bottom of the barrel is the stuff that is cooked instead of dried, it has white encrusted coatings, bleached beans and the worst kinds of 'premature aging'.

Secondly is the fact that wet parchment coffee, especially if it has not been well fermented, washed and soaked, is sticky and will not flow freely between the convoluted channels of modern cascade or cross flow drying equipment. Bridging and hang-ups need special attention to design. Still today, this is usually met by a double drying operation. The coffee is 'skin dried' in a flat bed model drier, usually heavily stirred, with a lot of horsepower to minimise on parchment cracking, and once the stickiness is removed, the parchment is passed onto a 'single pass' rotary drier. This means that the hot air only passes once through the coffee and is then discharged. Single pass is fine when the coffee is wet, all the heat is absorbed in the initial evaporation of the surface moisture, the drying air is discharged at 100% relative humidity, and that is 100% efficiency, and there is no wastage. However, by the time that the parchment is separating from the surface of the beans, less than half way through the drying process, the heating air is being discharged at a relative humidity of only 40-50%, and this is gross inefficiency. Half of the heat energy put into a rotary coffee drier is usually blown to waste with little or no good effect..

Thirdly is the fact that the first models of coffee machinery were designed by European manufacturers for those East African tropical colonies close to 200 years ago. They were

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[1] http://scholarspace.manoa.hawaii.edu/handle/10125/6994

principally designed to finish off sun dried coffee. They were made of heavy castings, and because there was a surplus of coffee hulls available, the furnaces were built down to a price, rather than for efficient combustion. Heat exchange surfaces were woefully inadequate, but cheap to build and they did the job they were expected to do.

The modern manufacturers have done well to get rid of as many of the castings as possible and use light fabricated sheet steel. However, they have not done much at all about improving the heat transfer efficiency.

Sun dried coffee has always been regarded as of superior quality to a totally machine dried product. However, apart from the perceived problems of bleaching underripe silverskin and of alleviating ‘grassiness’, a 100% machine dried product should be only of minor lesser quality if sufficient care is taken.

Countercurrent flow drying, more efficient combustion of coffee hulls, and taking more time to dry the coffee more slowly will pay dividends in both quality and fuel and labour costs.[2] Indeed, if the coffee can be dried from ‘go to wo’ in one operation, in one single machine, the reduction in labour costs can balance out the additional drying time involved. . .. However, our traditional Coffee machinery is designed to run for more than 30 years or more, and the pain of tossing it out on the scrap heap is usually too much for our Bank Managers to bear. So, it is only when building a new factory, or expanding an existing operation that what I am suggesting may come to pass.

Initiating the Switch, from Unskilled to Skilled labour:

It is my considered opinion, that as a country develops and raises its standard of living, the amount of seasonal casual labour has to be gradually tailed off and machinery be used to reduce the drudgery, uncertainty and the seasonal nature of employment. Each succeeding level of mechanization, starting from hand tools and finishing with total automation, should increase the level of jobs that can support a higher level of payment and reduce the lower paid jobs. A workman with a spade can only work a hectare at most and be paid for what he can produce from that small area of land, but the capital investment necessary to employ him is only the price of a spade. Up the capital investment per workplace to buy a chinese two wheel walking tractor and it is easy to pay him a higher wage because he is producing more and the company prospers because of increased throughput. However, having invested in both the machinery and the skill of the workman, to keep him in the company he will need all year round employment. Invest in a four wheel tractor and his wages can go up again.

More efficient coffee drying machinery does not increase the capital investment that much above what machinery is presently available, but it will certainly improve the wages and tenure of employment of a corresponding lower number of handpicked loyal staff.

Of equal concern could be the loss of work and income of those peasant workers who earn a living by cutting and transporting firewood out of the indigenous tropical forest and Stacking it up on the roadside for sale to the coffee industry.. However, it is ultimately to the overall good of the country and preservation of its indigenous resources that is the greater good. A more efficient and profitable coffee industry should, in the final analysis, be able to offer better prices to its growers and thereby increase production and raise the standard of living of both the farmers who grow the coffee and the those company employees who process it.

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Starting with Combustion:

Coffee hulls are an ideal fuel for automation. [3] They can be transported around the factory with air, ie. pneumatics, and burn very nicely in suspension

[2] http://aciar.gov.au/files/node/316/grain_drying_in_asia_part_4_86776.pdf

[3] http://www.northsouth.ethz.ch/programmes/sawiris/sawiris_4

with practically no smoke. However, as stated, most coffee drying furnaces use too much combustion air and have too small a heat exchanger area. Therefore too much hot combustion gas goes to waste up the chimney. This has been measured at more than 50%. losses by E.A Gilmour in his P.N.G. Paper 'Coffee drying'. The way to eliminate that massive loss of heat and drying capacity is to gasify the hulls in a cyclone burner, using a double combustion process which gives a very clean stream of hot air, where all the heat is in the drying stream, including the gaseous products of combustion.[4] Wood out of a forest contains a lot of moisture and its heating value and its drying capacity are much reduced because of that. Because coffee hulls are so clean and so dry, there is practically no moisture in the direct fired gas stream[5], and its drying power is more than double that of a conventional operation using forest wood through a heat exchanger trying to dry ambient air which normally has a very high relative humidity in the tropics.

Direct Firing is O.K.:

I did not come to this conclusion from only theoretical considerations. In the 1960s as part of my training in Industrial Chemistry, we were involved with a herb drier that was direct fired with domestic coal gas, which does have an odour. Nevertheless, close chemical analysis of those herbs gave no sign at all of any contamination. The combustion process itself removed all the odours. In the early 1990s I was running a coffee factory with an old rotary McKinnon Drier, which used a 'direct combustion' diesel burner where there was no flue and all the combustion products went past the coffee. The burner was getting old and had to be under constant attention to minimise the smoke of badly combusted diesel fuel which very definitely had an odour. The first time I was presented with a batch of parchment blackened with diesel soot, I was in agony. However I was assured by the old workman in charge that it was alright?? I followed that batch of coffee right through the sales chain to the export consignment and past a team of liquorers and nobody turned a hair. I agonised that the old Bentall Huller would have screwed that blackened parchment up against the green bean and wiped enough diesel onto the bean surfaces to really do great damage. But the dry parchment seemed to have absorbed all the possible oiliness and the parchment itself was an effective barrier to keep any odour away from the bean. Every time the dockets came back, they were A grade first quality!! I did manage to convert over to an impact huller where the majority of the parchment got removed without any screwing or rubbing contact on the beans, but even though that change eased my conscience, it did not improve the quality of our coffee.

From that point on, I dug into the question of direct fired combustion heaters. If the coffee hulls were burnt very cleanly, then the combustion air could be mixed in with the drying air, and there was no need for a heat exchanger and especially, no need for a chimney! This was good for two reasons. Firstly, by modifying the existing cyclone burner, made of 316 stainless steel and reducing the air intake but pushing it in at a slightly higher pressure, I could produce a 'wood gas' or 'producer gas'. That is a combustible mix of carbon monoxide and hydrogen, after the style of the 'gasifiers' that ran so many motor vehicles in the second world war. This combustible gas, from only one burner unit, could be piped across the factory into several secondary pot burner units each close coupled to its own drier. By first combusting the hulls in a cyclone burner, the very small amount of ash was removed at this stage, out the bottom of the cyclone. Then the hot gas, still retaining

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[4] www.hindawi.com/journals/jc/2011/303168/

[5] http://news.mak.ac.ug/documents/Makfiles/aet2011/Lugano_I.pdf

most of its sensible heat from the initial combustion, but only at 300-400oC, not even at dull red heat, was filtered and distributed through lagged light steel flues to the secondary pot burners. Those secondary burners produced a beautiful clear violet flame without a fleck of red from unburnt carbon[6], and the hot air had absolutely no odour at all. At the factory in question that one burner unit ran three Guardiola type driers with the same amount of husk that it previously took to run one. The big reduction however was in corrosion. No heat exchangers required! And, piping hot producer gas, which has no oxygen in it, meant that there was no black oxide corrosion of the light steel welded tubing that transported the gas to each dryer.[7] The much smaller individual pot burners were literally made out of gallon paint cans in the middle of 200 litre drums, and such was the temperature lowering that they never even lost their shine.

A second reason for going down this pathway was because our electricity charges were high, and being a typical unreliable third world country, we had to have our own standby generator on hand for reliability. I was anxious to run our gas through that diesel genset, dual fuel, and then use the waste heat from the engine to dry some of the coffee. That would be killing two birds--! However, my contract ran out before this could be suitably achieved.

My Prior to Coffee Experience:

During the first oil shock in the early 1970s I had ran a whole village industry workshop on a remote Pacific Island on wood fired producer gas. Producer gas is very dry and tended to lick the lubrication off the cylinder walls of an engine. But in a Pacific Islands salt air environment, Toyota Truck bodies rusted out very quickly, and used FJ engines used enough extra oil to make a good wearing combination. After the second oil shock in 1979, at our local Mission High school, we ran a diesel engine generator set on producer gas, using the engine cooling water, via a heat exchanger, as hot water for the kitchens and shower blocks. It is still surprising to me that this sort of technology has not been used in the coffee industry before. It is of course equally possible to generate Biogas from the factory wastewaters.

Direct firing with biogas is even simpler than with hulls. However, it is much more efficient to fuel ones electricity supply and plantation vehicles with biogas and once again utilise the waste heat from the electrical generator, which is about the right temperature, less than 50oC, and dry as much as possible of the coffee with that.

I was brought up on a farm in New Zealand, just when the advent of grain drying in the 50s & 60s revolutionized the industry in the deep south, where my family lived. Previously, because of the high rainfall in the autumn, we could only grow oats, but now the province suddenly could harvest wheat and barley with 20% moisture content, put it though a grain drier, and still sell a premium quality grain. Co-operative Grain drying facilities blossomed everywhere, and many different types and technologies were experimented with. It is from this past experience that I now advocate some changes in our coffee industry.

New Patterns of Drying Machinery.

The major problem with stirred pan and other types of flat bed driers is that the full heat of the machine initially impacts on wet parchment and it is so intense and the difference in temperatures is so great that the parchment skin dries

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[6] http://gasifiers.bioenergylists.org/files/Continuous-Flow%20Rice%20Husk%20Gasifier%20for%20Small-Scale%20Thermal%20Applications_0.pdf

[7] http://www.hfdepo.com/hfdepo/en/newsinfo.asp?id=217

and shrinks over the still swollen and wet bean inside. Unless the bed is stirred vigorously to keep the coffee well mixed, then cracking of the parchment occurs. That mixing takes around 10 kilowatts of horsepower, and a very stiffly reinforced machine to stand the twisting forces involved, . With some parchment still intact, some parchment cracked and some beans loosing their parchment coating altogether, one is faced with very uneven drying conditions and possible case hardening of the more exposed beans in an effort to dry the rest. Very experienced operators can holt the drying process at the point where a few days in a conditioning bin will allow the moisture content to even out at the correct value. However, this is extra time extra handling and extra equipment, and requires the need for exceptionally skilled workmen.

Counter Current Flow:

The obvious counter to all of these conditions is to make sure that the warmest air, with the lowest relative humidity, and the highest drying power, only impacts on the driest beans which require a relative humidity of less than 50% to get out those final few points of moisture. However, having done this, it should not be wasted, as it is in a Guardiola type rotary dryer. That air should then be pushed up though a slowly descending bed of higher moisture parchment coffee contained in a light steel silo to finally exit through the top surface with no need of any stirring required. The wet beans being slowly added at the top, past the gas exiting with its maximum load of moisture and the minimum of temperature difference at all stages between the beans and the air passing by them. What is required therefore is a wide flat bottomed silo from 10 to 18 metres in diameter, with no taper of the walls so that even wet sticky coffee parchment cannot lodge or stick to anything. Instead it can only fall vertically and relatively evenly as the dry coffee is pulled out from the bottom of the silo with a sweep augur. This type of drier is comparatively recent in the grain drying industry, but unlike equally modern cascade type equipment, is ideal for drying coffee. The depth of coffee at start up should be minimal and at reduced temperature until a steady gradient of moisture content down through the bed is achieved. Then the bed can be built up to be 2-3 metres deep Such a drying profile will easily take on a 'surge' volume as big as half a meter. Half a meter depth in a 10 meter wide silo is 40 cubic meters of wet coffee that can be accommodated at one time! That's equivalent to around 250 tonnes of cherry. That 'surge' will be slowly and continuously moved down to the base of the silo and taken out the flat wide bottom by a sweep auger that slowly works its way around the bottom pulling the driest layer of coffee at the bottom of the bed into a central discharge hopper and then either lifted up a central vertical auger, or pulled out underneath the slats bringing in the hot air, and augered or conveyor belted to the next stage. Once established, this type of operation can be continuous, 24/7, throughout the peak of season ripening period.

For Ultimate Quality:

To dry ones coffee in a total machine operation, may well produce a better quality than ones previous product, but it will not be the best quality possible. To get a good blue green colour of bean, and a mild flavour, it is still necessary to get enough direct sunlight on the parchment to bleach the chlorophyll out of the silverskin. That is best done first of all when the parchment is still wet and translucent, and it is possible to see the green colour of under ripe silverskin through it. It is surprising that even on a cloudy day the sky will still reflect enough light to give a significant reduction in grassiness. So, every where it is possible to get any drying at all out in the open air in one day, and the gain in quality ranks higher than the increased labour cost, it should be attempted. However, do not leave it out over night. Even if the coffee is still damp it should be put straight into the drier at the end of that day to minimise on mould spore germination. See comments in the microbiology paper for what happens should mould spores germinate on the parchment surface! From that point on the parchment coffee should be dried down to 12% moisture level in one counter current operation without further handling.

If the weather is so bad that there is no hope of open air drying on the day that the coffee gets its final wash, then a 100% mechanical operation will be required. Because there is so much moisture in dripping wet parchement , 50-60% , it will take at least two drying silos in tandem, to give both a deep enough bed, and a sufficient volume of air to carry off all the moisture. This does have some spinoff in that the first stage of drying can be run at a higher temperature, because the evaporative cooling of the excessive moisture keeps the beans cool, despite the heat. According to Rene Wilbaux, FAO Agricultural Engineering Bulletin No60, 1961, and a very notable authority, the initial higher temperature lifts off all the silverskin with no adhesion. Furthermore, he says that the initial faster movement of moisture moves the chlorogenic acid out to the surface and gives a deeper blue green colour rather than a more typical yellow green. Good bean colour and no baked on silverskin are both highly desirable. So, if one is running two silos in tandem, run the first silo at 60-70oC and only one meter deep of wet parchment and get down to just the parchment separation stage, and then run the second at 2-3 meters depth and 45oC. If initial sun drying is possible, drop the temperature of the first stage to 50oC See the continuous flow pattern of the figure below. It is of further advantage that all the heat put into the coffee beans, to achieve moisture transfer, can be reclaimed by finally blowing just dry air through the storage silo,, to achieve cooling by additional moisture removal. That is a further small improvement in overall efficiency.

Following on the Wilbeau pattern, it would appear that the ideal situation would be to combine sun drying with a machine assist, in the initial process of evaporating the surface water from wet parchment. However, I do not know of such a system at present.

Why Keep the Temperature Down?

Coffee beans are recalcitrant! That means that they are ready to germinate and grow, the moment the cherry is picked, QV. Article 'The Great Millennial Mistake", and that germination factor is very sensitive to damage. The larger the extremes of temperature that the beans are subjected to, the more likely they are to die. It is only in the last few years,[8] that research has been done on the subtleties of flavour established by maintaining the viability of the majority of beans up to the point of roasting. For more details on this aspect of 'Quality Maintenance', see chapter 3 of the Microbiology series.

No Design Costs Involved:

Rather than the expense of designing completely new machinery from scratch, it should be possible to buy in the right type of grain drier, a tapered sweep augur continuous flow type, run it for a time and then make any adaptions required. Suitable types and systems may be seen on the Internet at;
http://www.rekord.com/grain%20pages/shivvers_dryers.htm
or http://www.grainsystems.com/english/mathand/sweeps/swstnd.htm,
, http://www.brockgrain.com/products.php?product_id=319,
, http://www.alliedgrainsystems.com.au/farm_unload.htm

[8] http://www.ncbi.nlm.nih.gov/pubmed/16547871

And, as usual there are lower cost Asian and European manufacturers in on the game as well! http://www.himfr.com/d-p1124382947420157000-Auger_Grain_Auger_Combine_Harvester_Auger/
http://www.himfr.com/d-p1124285217320119500-Sweep_Auger/
Even if coffee is not mentioned, look for those that speak of Maize or Corn.

While it is possible to buy a drying silo 18 metres in diameter, that could easily continuously handle a factory taking in 200 tonnes of cherry a day, it would be much preferable to start with say two 10 metre models which could be individually experimented with, or preferably worked in tandem, and which would give a much better turndown ration at the beginning and end of the season.

The Basic Calculation:

One tonne of Green bean produces 250kgs of kiln dry hulls.
One tonne of water requires 970btus/lbx2.2 = 2,134,000 Btus/kg to evaporate it.
Kiln dry wood will produce 8000btus/lb.x2.2 =17,600 Btus/kg.
So, we may assume that one tonne of green bean will provide a theoretical heat equivalent of 250 x 17,600 = 4,400,000 Btus. That's more than double the theoretical requirement.
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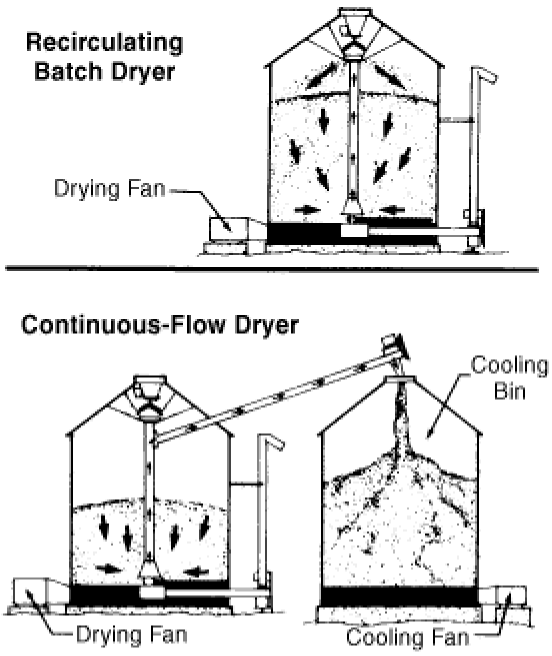
In theory, One tonne of green bean provides enough heat energy from dry hulls to dry twice its own weight of wet parchment. However, the practicalities are that even with the best equipment 50% efficiency Is only just attainable, and a certain amount of sun drying is required, not only for Reasons of quality but also to stay in the black with fuel reserves.



Keeping the Coffee Dry:

It should also be pointed out that storing coffee in metal silos, especially out in the open, is not a good idea! Direct tropical sunshine on a metal silo will cause considerable fluctuations in temperature from day to night. This will set up thermal convection currents inside the silo with the air around the beans, and that will transfer moisture from the centre to the outsides of the silo. Any part of the silo that gets past 14% moisture levels will start to grow mould, and that is very definitely not a good idea. I said earlier that conditioning bins inside a building maybe an extra expense, but if the alternative is outdoor metal silos, then go for those bins. Made square, from internally braced builders plywood, a nest of 4 or more bins will take the absolute minimum of materials. More details are given in Chapter three of the Microbiology series. A domestic table fan blowing underneath a bed of coffee up to 3 metres deep will move air up through the bed at around 5 meters per minute, which can be used to alter moisture content by one of two percentage points either way, depending on the relative humidity of the air at the time the fans are used.

Pneumatic Transportation:

I am also a 'believer'in the use of pneumatic grain transfer equipment. Wheeling barrows and bags of parchment from one operation to another is labour intensive. The use of vertical elevators and storage bins between each operation in a line of coffee processing machinery is fine, but if there is any distance involved, the height of elevator required becomes excessive. And separation of dust and loose hulls can be a problem. There are many European and American manufacturers like Kongskilde [9] [10] [11] who produce pneumatic piping systems, with all the relevant attachments to fully, or semi automate transfer of Coffee parchment and green bean. This piping system is also ideal for transferring hot gas for combustion, if it is suitably insulated to preserve heat.

As usual, I am happy to further discuss any of these points mentioned above, with anyone genuinely interested in the subject.

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[9] http://www.devree.com.au/OK-pipe-system-sales-perth.asp
[10] http://www.valmont.com/valmont/markets/agriculture-and-irrigation/grain-handling

[11] http://search.gmdu.net/b/Grain%20Dryer.html