

The Cow Comfort Link to Milk Quality

Nigel B. Cook MRCVS
University of Wisconsin-Madison
School of Veterinary Medicine
Madison, Wisconsin

Published in Proceedings of the NMC 2004 Regional Meeting, Bloomington, Minnesota, July 29-30, 2004

Introduction

It is commonly accepted that the rate of new intra-mammary infection is related to the number of bacteria that the teat end is exposed to (Neave et al., 1966), and several studies have made associations between clean housing, clean cows and lower bulk tank somatic cell counts (Bodoh et al., 1976; Barkema et al., 1998; Barkema et al., 1999). In addition, Bartlett et al. (1992) found that an index of environmental sanitation based on the amount of manure on the cow and in her environment was a predictor of the occurrence of coliform mastitis, and Ward et al. (2002) noted that in four study herds, the lowest incidence of mastitis occurred in the herd with the cleanest cows and the most satisfactory beds.

There is therefore a general assumption that high standards of cow comfort and the management of clean cows equates to improved milk quality. The North American dairy industry is currently in the midst of a cow comfort revolution driven by improved economics and a new awareness of the influence of stall design on cow well-being (Anderson, 2002; 2003), with benefits in lameness prevalence in particular (Cook, 2003). However, changes may not always be associated with improvements in ease of management, and one of the greatest concerns for the farmer is the problem of keeping cows clean, while providing larger more comfortable stalls. An unused stall is definitely a clean stall, but altered daily patterns of stall use behavior may create lameness problems. In contrast, a used stall is often a dirty stall (Gaworski et al., 2003) which is undesirable for udder health. Improvements in cow comfort may therefore not always go hand in hand with improved milk quality and we must find the balance in our stall design alterations so that cows remain clean, and stall use behavior is not compromised. It has also been common for us to find high rates of new infection with environmental pathogens on farms with apparently clean cows. The importance of bedding management in these situations cannot therefore be underestimated.

This paper will focus on how to create dairy housing that improves cow comfort, keeps cows clean and dry, and improves milk quality by reducing the rate of infection with environmental pathogens. Clean, dry, and comfortable. These three words are easy to say, but difficult to deliver in the real world of dairy farming. Let us examine separately the aspects of housing which deliver clean and dry cows and stalls, and designs which keep cows comfortable and reduce levels of lameness in more detail.

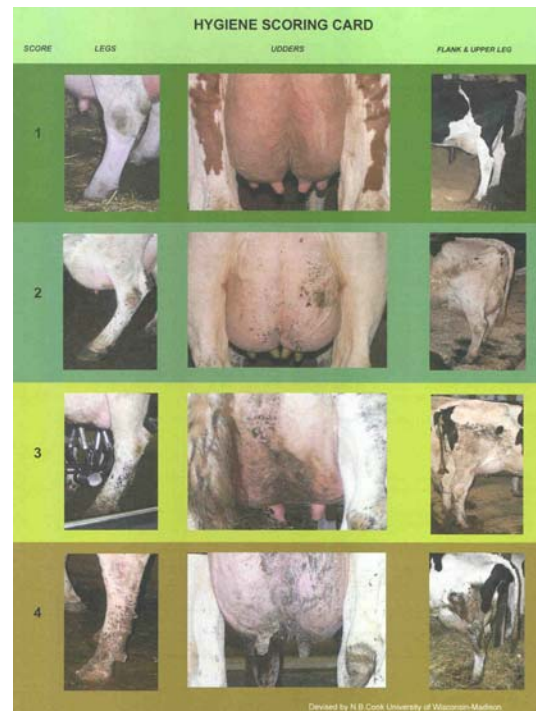
Delivering the ‘Clean and Dry’ Components of Clean, Dry and Comfortable

In order to assess cow cleanliness, we must have an objective way of looking at the cow in order to communicate that she is either “clean” or “dirty”. Hygiene scoring has been commonly used on our routine herd investigations to assess cow cleanliness and deliver information regarding the mechanisms that transfer manure to the udder and teats.

There are four basic transfer mechanisms, and the relative importance of each differs with the type of housing under consideration:

1. **Direct Transfer.** Cows may lie down in a manure contaminated stall or bedded area (or sometimes in a traffic alley!) and transfer bacteria directly to the udder.
2. **Leg Transfer.** Cows may walk through manure, coating their feet and legs, which transfers bacteria to the teat ends when the cow lies down and the udder comes to rest on one of the hind feet (Abe, 1999).
3. **Splash Transfer.** Cows walking through deep liquid slurry will splash manure up toward the udder.
4. **Tail Transfer.** In some situations, the tail may become heavily contaminated with manure and transfer bacteria to the rear udder and flank areas (Abe, 1999).

Figure 1. Hygiene Scoring System used on herd investigations, scoring cows in three zones; the udder, the lower leg and the upper leg and flank zones, using a four point scale.



We therefore use a hygiene scoring system which records the level of manure contamination using a 4-point scale (where 1=clean, 2=slightly dirty, 3= moderately dirty and 4= excessively dirty) in three zones; namely the udder, the lower legs and the upper leg and flank zones (Cook, 2002). A pdf file is available for download at www.vetmed.wisc.edu/dms/fapm/forms.htm. It is pointless communicating an average score for the cow, or even for each zone. We are interested in the population that is considered “too dirty” – which is a threshold problem. We therefore record the proportion of scores 3 and 4 (which we argue represents scores that are “too dirty”) for each zone. This has been an effective way of raising the difficult subject of cow hygiene and communicating the information in a way that provides information on why the animals are too dirty. It has been most effectively used within herd by making comparison between pens. However, crude comparisons can also be made between herds. Data from 46 farms are presented in table 1 for free stall and tie stall herds. Other authors have confirmed that hygiene

scoring is reflected in changes in udder health, giving the system some validity (Reneau et al., 2003; Schreiner and Ruegg, 2003).

Table 1. Mean proportion of hygiene scores 3 and 4 for each zone for cows in 46 Wisconsin dairy herds by housing type (36 Freestall and 10 Tiestall). Target score refers to performance of the best herds.

| Housing Type | Proportion Hygiene Scores 3 and 4 (%) | | |
|---------------------------|---------------------------------------|------------|-----------------------|
| | Udders | Lower Legs | Upper Legs and Flanks |
| Free stall (mean, target) | 21 (5) | 58 (24) | 17 (0) |
| Tie stall (mean, target) | 17 (5) | 26 (9) | 24 (5) |

Tie Stall Cows

Although the mean proportion of udders scoring too dirty are similar between tie stall and free stall cows, the main mechanism of contamination is different. Tie stall cows in general have excellent leg hygiene, as they do not have to walk up and down manure filled alleys all day long. They do however have to spend around 21h per day standing, lying, milking, feeding and drinking in their stall. The chances of manure contamination of the stall bed are therefore increased compared to the free stall cow – and this is reflected in the dirtier upper leg and flank scores in these herds. The chances of direct transfer are therefore high. Clearly, with cows spending such a long time in their stalls, in close proximity to manure in the gutter, the possibility of tail transfer also exists. Only one study examining the influence of tail transfer in a tie stall barn has been reported, where the barn was fitted with covered gutters. Flank hygiene was significantly worse in the undocked cows, but there was no difference in udder hygiene (Eicher et al., 2001). In barns with uncovered gutters, unclipped undocked tails may transfer manure to the flank and rear udder, and on farms that practice hanging tails up on string out of the gutter, flanks appear cleaner. However, the focus of udder hygiene must be on transfer of manure to the teat end, and it is questionable whether tail transfer is a major issue. The risk, if present, may be reduced by using grates to cover the gutter and to regularly brush these off at each milking.

The main aim of tie stall housing is to design a stall where manure and urine are deposited into the manure gutter and not onto the stall platform. Although banned in some countries, electric cow trainer (ECT) use has been reported to keep cows and stalls cleaner when located correctly, 48 inches from the rear lip of the stall platform and 2 inches above the back-line of the cow (Bergsten and Pettersson, 1992). It is not acceptable to leave ECTs on without regular adjustments to their location.

Free Stall Cows

In contrast, free stall cows must spend around 9 h/d feeding, drinking, milking and socializing in manure filled alley ways. They generally have poorer leg hygiene than tie stall cows, increasing

the chances of leg and splash transfer. Differences in leg hygiene between pens will be determined by the sum of several factors including:

1. **Stocking Rate.** The more cows in a pen, the more manure they produce, the deeper it will be.
2. **Stage of Lactation.** Ward et al. (2002) found that early lactation cows were dirtier than dry cows and cows in mid to late lactation, and they associated this with the production of looser feces in this group.
3. **Activity.** Early lactation groups will be eating more, and they will be handled more for vaccination, breeding programs, and health monitoring. They will also have more cows in heat, which disrupts the pen and leads to increased traffic in the alleys.
4. **Pen design.** 3-row pens have 20% less alley area than 2-row pens for the same amount of manure.
5. **Drainage.** Alley slope is important for drainage. They should slope at least 1% from end to end and away from the rear of the stall to avoid pooling below the tail.
6. **Scraping frequency.** Alleys are scraped at each milking or automatically on a variable cycle. A minimum of three times a day is recommended.

Thus, cows in early lactation, housed in overstocked 3-row pens, scraped only twice daily, generally have the worst leg hygiene scores. Once in the stall, manure may also be transferred to the udder by direct transfer if there is a design fault. Manure may be deposited in the stall when the cow is standing; which is primarily prevented by neck rail location in free stalls, and when the cow is lying down – especially when she is positioned diagonally across the stall. The issue of tail transfer is a hot topic and I believe interconnected with the diagonal lying issue. We shall therefore consider neck rail location and factors contributing to diagonal lying and tail transfer.

Neck Rail Location

Determining the correct vertical and horizontal location of the neck rail is most troublesome. Modern stall designs recommend a vertical height above the stall surface of 48 to 50 inches in mattress stalls. In loose bedded sand stalls, the aim must be to maintain the neck rail between 44 and 50 inches above the bedded surface. The horizontal location is perhaps more important, and more difficult to locate correctly. It is common to find the neck rail located at 57 to 68 inches from the rear curb in both sand and mattress stalls.

It is unacceptable to locate the neck rail in a position where the cow must hit it in order to stand in the stall. However, we are now realizing that recommendations for mattress stalls and sand stalls must differ. We now know that stall standing behavior is different in cows housed in sand and mattress stall barns with similar stall designs. While the behavior of non-lame cows is similar in both types of housing, the behavior of lame cows is markedly different. Lame cows spend up to 4.3 h/d more standing in the stall in mattress herds, compared to lame cows in sand stall herds (Cook et al., 2004).

In a mattress stall, the neck rail should be located vertically above the brisket locator or around 68 to 72 inches from the rear curb, depending on the size of the cow. This location allows the cow to stand square in the stall with all four feet on the platform. However, many farmers have

commented that the same location in sand stalls results in too much manure and urine being deposited in the rear of the stall – because of the raised rear curb, which the cow will be reluctant to stand on with her rear feet. This curb effectively reduces the length of the stall surface, and makes the cow stand diagonally across the stall. We know that cows in sand stalls spend much of their stall standing time perching with 2 feet on the platform and the rear 2 feet in the alley, and that lame cows in sand stalls do not spend excessive amounts of time standing in the stall in comparison to mattress barns with similar stall dimensions. Therefore, our recommendation in stalls with loops that locate the neck rail 44-50 inches vertically above the stall surface, is to move the neck rail from above the brisket locator toward the rear, a distance equivalent to the width of the rear curb. We therefore prefer curbs that are not too wide. Thus, in a mature cow sand stall with 72 inches from the rear lip of the curb to the brisket locator, with a 6 inch wide curb, the neck rail should be located $72 - 6 = 66$ inches from the rear lip of the curb. For first lactation heifers with 68 inches from the rear curb to the brisket locator, the neck rail should be located $68 - 6 = 62$ inches from the rear lip of the curb. In stalls with neck rails lower than 44 inches, the farmer must be prepared to make further adjustments to the neck rail location to ensure that the cow can rise without hitting the rail. At this location, the cow will be forced to perch, with the rear feet in the alley. We are prepared to tolerate this for two reasons; firstly we now know that cows do not stand in the stalls for prolonged periods when lame in sand herds, and secondly, the elevation of the front feet in a sand stall is much less than that in a mattress stall, reducing the stresses on the rear feet while perching.

Table 2. Stall dimensions from 12 existing Wisconsin free stall herds built in the last 4 years (6 sand and 6 mattress facilities) compared to new recommendations for first lactation, mature cow and pre-fresh cow groups.

| Stall Dimension (inches) | Existing Dimension Audit (12 herds) | | New Recommendations | | |
|---|-------------------------------------|--------------------------------|--|--|---|
| | Mattress Freestalls (mean 6 herds) | Sand Freestalls (mean 6 herds) | First Lactation | Mature Cow | Pre-Fresh |
| Total stall length facing wall | 100 | 105 | 108 | 120 | 120 |
| Head to head platform | 179 | 181 | 204 | 216 | 216 |
| Stall length from rear curb to brisket board | 66.5 | 67.0 | 68-70 | 70-72 | 72 |
| Stall divider placement on center (width) | 45.8 | 45.1 | 48 | 50 | 54 |
| Height of brisket board | 6.5 | 6.2 | 4 | 4 | 4 |
| Height of lower divider rail | 11.9 | 13.7 | 11 | 11 | 11 |
| Height below neck rail | 45.8 | 46.7 | 48 | 50 | 50 |
| Horizontal distance between rear curb and neck rail | 64.5 | 64.5 | 68-70 (minus width of rear curb in sand stalls) | 70-72 (minus width of rear curb in sand stalls) | 72 (minus width of rear curb in sand stalls) |
| Rear curb height | 10.6 | 9.1 | 8 | 8 | 8 |

Diagonal Lying

Cows that lie diagonally deposit manure in the corner of the stall and contaminate the bedding material with fecal matter. Manure is transferred directly to the flank and udder. Once located diagonally across the stall, the tail is more likely to hang in the alley and potentially lead to tail

transfer problems. Farmers react by moving the neck rail closer to the rear curb, and /or by replacing the divider with a version with a longer lower divider rail, or worse still, rotating the existing divider through 180° – so that an extended lower divider rail acts to keep the cow straight in the stall. Soiled tails are docked in order to keep the cows cleaner. Such draconian measures are unnecessary and we do not recommend them. If we just spend a moment to understand why the cow is choosing to lie down across the stall, rather than straight in the stall, the problems may easily be fixed.

Diagonal lying is a complex issue caused by a variety of stall design factors – involving standing position, mechanical and social obstructions. The stall design must allow for the normal rising and lying movements of the dairy cow – described elsewhere (Nordlund and Cook, 2003; Anderson, 2003). In particular, we must provide forward lunge room for the head, an unobstructed bob zone (the vertical space at the furthest point of the lunge between the stall surface and a height above it of around 40”) and we must allow for the forward stride of the forelimb as she rises, so that the leg can take the weight of the cow and facilitate the rising motion. Diagonal lying is therefore in response to a failure to meet some or all of these requirements. Let us consider some of these failures.

1. Standing Position

If the brisket locator or neck rail is located too near the rear curb in a mattress stall, then the only way the cow can stand in the stall is diagonally across it. From this position, it is likely that she will lie diagonally as well. In a sand stall, the neck rail must be located so that the cow perches in the stall when standing. Recommendations for stall length and distance from curb to brisket locator are given in Table 2. Figure 2 shows a cow standing diagonally in a sand stall, avoiding the rear curb. Note where the manure has been deposited.

Figure 2. Diagonal standing in a sand free stall with manure landing in the rear of the stall



2. Mechanical Obstructions

a. Short Stall Length

Anderson (2003) now recommends that stalls located against a solid side wall should be 10 feet long to allow for forward lunging in the largest cows in the herd. Stalls 7.5 feet or less force the majority of cows to side lunge into the adjacent stall. To rise and lie down in such a stall, the cow must locate herself diagonally across it. For successful side lunging, the upper edge of the lower divider rail must be no higher than 11-12 inches above the stall surface. The biggest stall disasters we see are where a narrow loop has been installed in a short stall. In this situation, the cow struggles to lunge both forwards and to the side.

b. Lunge Obstructions

These are commonly seen in head to head stalls. Wires, bars and wooden barriers are placed across the front of the stall, to prevent cows from passing through underneath the neck rail – and potentially becoming entrapped. Unfortunately, if the lower edge of this barrier is lower than 40” above the stall surface, it obstructs the lunge movement of the head when lying and rising. With modern stalls and high neck rails, a deterrent wire coated with polypropylene tubing may be safely located 40-42” above the stall surface across the front of head to head stalls. Anything lower or more substantial will force the cow to lunge diagonally across the stall in order to avoid the obstruction, and consequently end up lying diagonally.

c. Bob Zone Violations

The bob zone is frequently affected by the presence of horizontal mounting bars for the dividers – what we refer to as “chin-clipper bars”, mounds of sand bedding and concrete fills behind high brisket boards. The presence of these obstructions force the cow to rise with her head up in the air, rather than with her chin almost touching the ground, which puts more weight on the rear feet and increases the risk of slipping and injury. Cows will lunge to the side to try and avoid the obstruction, but may only do so if they are small in stature (ie first lactation heifers) or the stall is wider than normal. (We can use this fact to our benefit when making modifications to head to head stalls on a short platform to improve comfort and use).

Figure 3. This cow is unable to take a forward stride because of the 10 inch high brisket board at the front of the stall. To get up, she shuffles back on her knees until her rear legs are in the alley. From this point she can thrust the front leg forward and complete the rising movement.

d. High Brisket Locators

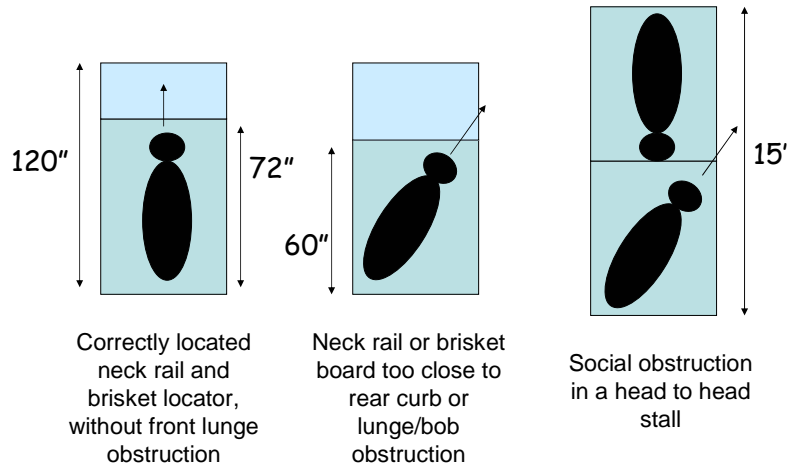
The cow must be able to thrust her front leg forward when rising, if we are to avoid compromising her ability to get up in the stall easily. To do so, brisket locators – which are used to locate the cow in the stall when she is lying down, must be no higher than 4-5” above the stall surface. Any higher, and the cow must jamb her leg downward rather than forward, which increases stresses on her feet and legs. Some cows will rise on their knees and shuffle back in the stall and complete the rising movement with their rear legs in the alley (Figure 3).



Wooden brisket boards that are higher than 5 inches, concrete brisket areas and even ‘polypillows’ that are mounted too high all compromise the ability of the cow to perform this forward stride with the front leg. In an attempt to cope, the cow will lie diagonally in the stall so that she can borrow some space for her leg to move forward before hitting the brisket locator. The sound of front feet hitting boards is a tell tail sign that this is a major problem in the barn.

Long lower divider rails, if used in these barns, will be rubbed shiny and distorted by the pressure of cows leaning against them – because the reason for diagonal lying has not been removed.

Figure 4. Mechanical and social obstructions leading to diagonal standing and lying in free stalls against a solid side wall and in head to head stalls.



3. Social Obstructions

Even when we solve all of the other mechanical obstructions, we are still left with one more in head to head stalls (Figure 4). If we build head to head stalls on a 15’ platform, cows will rarely front lunge into a cow lying in the opposite stall. Cows may only borrow space from an adjacent stall if it is vacant. In order to move the heads apart and allow forward lunging in head to head stalls, the stall platform must be 18 feet. (Anderson, 2003). Even at this length, we must still allow for side lunging, with a wide loop divider, and fixings must be modified to resist stresses on the divider.

Thus, when troubleshooting diagonal lying problems we must consider each of the factors related to standing position, mechanical obstructions and social obstructions and attempt to resolve each of them. In head to head stalls on a short platform, despite alteration to all of the other factors, we will still have to live with

Figure 5. Diagonally lying in a short narrow stall in a barn with automatic alley scrapers results in many cows having heavily contaminated tails, which transfer manure to the upper legs and flanks and rear udder.



some diagonal lying due to social obstructions. Most of the herds that make changes which improve stall use in these head to head stalls tolerate the extra effort required to remove manure from the rear edge of the stall, because of the other perceived benefits of improved stall use and cow comfort.

Two studies on tail transfer in free stall housed dairy cows found no significant improvement in either cleanliness or milk quality in docked cows compared to undocked controls (Tucker et al., 2001; Schreiner and Ruegg, 2002). These data contrast with the strongly held belief by many farmers that tail docking keeps cows cleaner and improves udder health. The two studies performed with negative findings represent very few herds (nine in total) and perhaps do not represent the vast spectrum of different types of free stall housing. In particular, where cows lie diagonally in short stalls in barns with automatic scrapers, they may have filthy tails and highly contaminated udders and flanks. The solution to the problem however, is not to remove the tail, but to solve the stall design issue and the diagonal lying.

Putting the ‘Comfort’ back into Clean, Dry and Comfortable

Designing a free stall that can be used successfully by a cow with a sore foot, which can also be maintained clean and dry, is the key challenge we must face in modern free stall facilities. The area of the stall has an effect on standing and lying behavior. We have already considered stall length and curb to brisket distance, but stall width is also important. Tucker et al., (2004) found that cows lay down for 1.2 h/d longer in wider stalls (52 vs 44 inches) and spent less time perching. We recommend stall widths of 48 inches for first lactation heifers, 50 inches for mature cows and 54 inches for pre-fresh cows, measured between dividers on center. Where mixed ages and sizes are penned together, we suggest using the smaller dimension, or be prepared to tolerate dirtier stalls. Herds switching to wider stalls have seen dramatic improvements in stall use and associated benefits in health and productivity.

In terms of stall surface and bedding choice, sand remains the gold standard – largely for its ability to maintain normal daily activity patterns in lame cows (Cook et al., 2004). It appears that because of its ability to provide traction, cows with sore feet can rise and lie down more easily than on a smooth mattress surface. We have however documented that cows on sand have a greater number of long lying bouts in excess of one hour than cows on a mattress surface – suggesting that improved cushion may also have an effect on lying behavior. Sand also has other benefits. Hygiene scores in cows in sand herds are on average better than for cows in mattress stall herds. In particular, udders are 50% cleaner in sand herds (Table 3).

Table 3. Least squares mean (SE) hygiene scores (Proportion scoring 3 and 4 for each zone) obtained independently by two observers from a minimum of 20 cows in the high group pen on 12 free stall herds (6 sand and 6 mattress) compared using 1-way ANOVA.

| | Sand | Mattress | SE | P |
|----------------------------|-------------|-----------------|-----------|----------|
| Udder | 16.7 | 33.3 | 4.2 | 0.02 |
| Lower Leg | 39.2 | 74.2 | 8.6 | 0.02 |
| Upper Leg and Flank | 1.7 | 11.7 | 2.1 | 0.01 |

We believe that the improved hygiene is due to one or a combination of the following factors:

- Sand appears to act as a cleaning agent, removing manure from the legs, udder and flanks
- Cows perch more in sand stalls with raised curbs and deposit manure in the alley rather than on the stall platform
- It is possible that lame cows are dirtier, they spend more time standing in the stall and their abnormal gait means that they may splash more during movement through the alleys. We now know that mattress free stall barns have more lame cows on average than sand free stall barns (Cook, 2003).

Although inert when fresh, sand material may harbor many millions of bacteria even when it appears grossly normal once contaminated with milk, urine and feces. We have had a number of clinical experiences with very high rates of clinical mastitis when coliform counts exceed 100,000 CFU/ml. Well managed stalls maintain the coliform count less than 5,000 CFUs/ml in our experience. These herds add fresh sand every 7 days, do not use tires or bedding retainers and generally use a coarse washed mason sand. Interestingly, it appears normal to find very high numbers of streptococci in sand, yet they do not appear to cause problems with clinical mastitis in most situations. Mechanisms of teat colonization may be different with sand compared with other organic bedding materials (Zdanowicz, 2002).

For those that do not wish to deal with sand laden manure, a mattress is an alternative to sand. There are data to suggest that of the types available, cows prefer the more cushioned varieties and we certainly do not recommend the use of solid rubber mats (Wagner-Storch et al., 2003). However, even with a cushioned mattress, there is a need for ample quantities of bedding – usually sawdust. Tucker et al. (In Press) showed a difference in daily lying time of 1.2 h/d in the same stalls with 16.5 lbs sawdust vs 2.2 lbs, and a difference of 2.2 h/d compared to no bedding. Bedding also helps reduce hock abrasion, another problem observed more in mattress than in sand stalls (Weary and Tazkun, 2000).

This presents a key problem in trying to find the balance between comfort and milk quality. Bacterial growth in organic bedding material is difficult to manage. In short, we believe that whatever bedding you use on the stall, it must be replaced completely every 24 h. Experiences in a 50 cow stanchion herd with 88 quarter cases /100 cows /year, 34% of which were due to *Klebsiella*, confirm this. Following a move to complete daily removal and refreshment of the sawdust bedding, clinical case rate dropped to 47 quarter cases /100 cows /year and *Klebsiella* infections dropped to only 6% of the clinical cases. Cows actually appeared a little dirtier on their flanks, as less bedding was being used at any one time – but the savings from improved milk quality amounted to \$148 per cow per year.

Summary

Clean, dry and comfortable. Three simple words that are difficult to achieve in the real world of dairy farming. However, with new information and experiences related to advances in stall design and with the lessons learned from progressive farmers willing to make changes to their barns, I believe that we can deliver improvements in both cow comfort and milk quality. Interestingly, high levels of udder infection may still occur in apparently clean cows if bedding

management is compromised. Conversely, to achieve bedding practices that lower new infection rates economically, we may have to tolerate slightly dirtier cows on mattress stalls. However, if we reduce surface cushion by using less bedding, lying times will be reduced which may have an adverse effect on lameness. The link between cow comfort and milk quality is a complex one – and we still have much to learn!

References

1. Abe, N. 1999. The deeper the “mud”, the dirtier the udder. *Hoard’s Dairyman* 144: 439.
2. Anderson, N. 2002. Observations on cow comfort using 24 hour time lapse video. Pages 27-34 in Proc. 12th Intl. Symp. Lameness in Ruminants. Orlando, Florida.
3. Anderson, N. 2003. Dairy cattle behavior: Cows interacting with their work place. Pages 10-22 in Proc. of 36th Annual Convention of American Association of Bovine Practitioners. Columbus, OH.
4. Barkema, H.W., Y.H. Schukken, T.J.G.M. Lam, M.L. Beiboer, G. Benedictus, A. Brand. 1998. Management practices associated with low, medium and high somatic cell count in bulk milk. *J Dairy Sci* 81: 1917-1927.
5. Barkema, H.W., J.D. Van der Ploeg, Y.H. Schukken, T.J.G.M. Lam, G. Benedictus, A. Brand. 1999. Management style and its association with bulk milk somatic cell count and incidence rate of clinical mastitis. *J Dairy Sci* 82:1655-1663.
6. Bartlett, P.C., G. Y. Miller, S. E. Lanc, and L. E. Heider. 1992. Managerial determinants of intramammary coliform and environmental Streptococci infections in Ohio dairy herds. *J Dairy Sci* 75:1241-1252.
7. Bergsten, C., and Pettersson, B. 1992. The cleanliness of cows tied in stalls and the health of their hooves as influenced by the use of electric trainers. *Prev Vet Med* 13: 229-238.
8. Bodoh, G.W., W.J. Battista, L.H. Schultz. 1976. Variation in somatic cell counts in Dairy Herd Improvement milk samples. *J Dairy Sci* 59:1119-1123.
9. Cook, N. B. 2002. The influence of barn design on dairy cow hygiene, lameness, and udder health. Pages 97-103 in Proc. of the 35th Ann. Conv. Amer. Assoc. Bov. Pract., Madison, WI. Amer. Assoc. Bov. Pract., Rome, GA.
10. Cook, N. B. 2003. Prevalence of lameness among dairy cattle in Wisconsin as a function of housing type and stall surface. *J. Am. Vet. Med. Assn.* 223 :1324-1328.
11. Cook, N.B, T.B. Bennett and K.V. Nordlund. 2004. Effect of free stall surface on daily activity patterns in dairy cows, with relevance to lameness prevalence. *J. Dairy Sci.* In Press.
12. Eicher, S.D., J.L. Morrow-Tesch, J. Albright, and R.E. Williams. 2001. Tail-docking alters fly numbers, fly-avoidance behaviors, and cleanliness, but not physiological measures. *J. Dairy Sci.* 84: 1822-1828.
13. Gaworski, M. A., C. B. Tucker, D. M. Weary, and M. L. Swift. 2003. Effects of stall design on dairy cattle behavior. Pages 139-146 in Proc. Dairy Housing Conf., Fort Worth, Texas. Amer. Soc. Agric. Engineers, St Joseph, MI.
14. Nordlund, K. V., and N. B. Cook. 2003. A flowchart for evaluating dairy cow free stalls. *Bovine Practitioner.* 37:89-96.
15. Neave., F.K., F.H. Dodd, R.G. Kingwill. 1966. A method on controlling udder disease. *Vet Rec* 78:521-725.
16. Reneau, J.K., A.J. Seykora, and B.J. Heins. 2003. Relationship of cow hygiene scores and SCC. Pages 362-363 in Proc. Natl. Mast. Coun. Madison, WI.

17. Schreiner, D.A., and P.L. Ruegg. 2002. Effects of tail docking on milk quality and cow cleanliness. *J. Dairy Sci.* 85: 2503-2511.
18. Schreiner, D.A., and P.L. Ruegg. 2003. Relationship between udder and leg hygiene scores and subclinical mastitis. *J. Dairy Sci.* 86: 3460-3465.
19. Tucker, C.B., D. Fraser and D.M. Weary. 2001. Tail docking dairy cattle: Effects on cow cleanliness and udder health. *J. Dairy Sci.* 84: 84-87.
20. Tucker, C. B., D. M. Weary, and D. Fraser. 2003. Effects of three types of free stall surfaces on preferences and stall usage by dairy cows. *J. Dairy Sci.* 86:521-529.
21. Tucker, C. B., D. M. Weary, and D. Fraser. 2004. Free-stall dimensions: Effects on preference and stall usage. *J. Dairy Sci.* 87: 1208-1216.
22. Wagner-Storch, A. M., R. W. Palmer, and D. W. Kammel. 2003. Factors affecting stall use for different free stall bases. *J. Dairy Sci.* 86:2253-2266.
23. Ward, W.R., J.W. Hughes, W.B. Faull, P.J. Cripps, J.P. Sutherland and J.E. Sutherst. 2002. Observational study of temperature, moisture, pH and bacteria in straw bedding, and fecal consistency, cleanliness and mastitis in cows in four dairy herds. *Vet. Rec.* 151:199-206.
24. Weary, D. M., and I. Tazskun. 2000. Hock lesions and free stall design. *J. Dairy Sci.* 83:697-702
25. Zdanowicz, M. 2002. Sand and sawdust bedding affect populations of coliforms, *Klebsiella* spp. and *Streptococcus* spp. on teat ends of dairy cows housed in freestalls. MS Thesis. University of British Columbia, Vancouver, Canada.